TELESCOPE MAKING 20

ISSN 0190-5570

The magazine *for, by,* and *about* telescope makers! Summer/Fall 1983

TELESCOPE MAKING

The magazine *for, by,* and *about* telescope makers!

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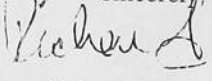
Editorial

TM #20 is finished at last and ready to send to the printer. It has the dubious distinction of being not only our biggest issue ever — at 64 pages — but also our latest. It's nearly two months behind schedule. That's due largely to my being out of the office for two weeks to see the solar eclipse in Indonesia in June, participating in the IAPPP's "Microcomputers in Astronomy" conference in July, and attending Stellafane in August. While none of these events by itself would have been unusually disruptive, a summer filled with such distractions meant that the orderly flow of work on your magazine suffered.

Well, to set things straight, we've decided to roll the Summer and Fall seasons into TM #20, and publish TM #21 as the Winter 83/84 date. This won't affect your subscription — you'll still get all the issues we owe you — we've simply slipped the production schedule back one season. To compensate for the delay, we're looking into making TM #21 a bigger issue than it would have been otherwise.

On the aesthetic side, we're dropping our new typesetter's too-dark Souvenir typeface entirely in favor of something called Garth Graphic. It looks better and it's easier to read than Souvenir. A few of the stories were finished before we made the change, so they appear in the old typeface, and a few more will appear in the next issue.

Sincerely,



Richard Berry
Editor

telescope making

TODAY

by
Robert E. Cox

Telescope making today! Is it any different than that of yesteryear? Having just spent my 45th year in attending and photographing telescope meetings I must reply with a definite yes! To properly understand the differences, let us go back 46 years to my first Stellafane meeting in 1937.

First, and most important, there are NO commercial exhibits! Everything on display is homemade from all kinds of assorted kinds of junk found in local scrap heaps or junk yards. Few instruments have more than 8 inches' aperture — and anything larger is viewed with awe and admiration. I did not realize this when I left for the meeting, but had I brought my newly completed 10-inch Newtonian, I would have had one of the largest instruments put on display.

Another very noticeable aspect of that first Stellafane was the apparent lack of young people. I was the youngest TM there, and as far as I could determine, the only other youngsters there were with their fathers who had the instruments.

Those telescopes that had clock drives usually weren't electric ones with fancy gear trains — instead they had varieties of spring drives using old alarm clock parts, phonograph drives, or falling weight devices.

Back in 1937 there was room to move about atop Breezy Hill. Telescopes were not crowded together as they have been in recent years. Today it seems there's usually hardly elbow room due to the many coming to the shrine of ATM activities!

Present were the "giants" of the hobby, Russell W. Porter, Albert G. Ingalls, Wally Everest, John Pierce — men whose efforts had resulted in the organized hobby of telescope making in America.

Almost all the telescopes were Newtonians. When Leo Scanlon of Pittsburgh brought a Cassegrainian, in spite of the recommendation in Chapter 10 of *Amateur Telescope Making*, "How to Make a Cassegrainian (And Why Not To)," it attracted a large crowd.

Working with the Perkin-Elmer Corporation in 1940 and the war years made Stellafane something I really looked forward to after the war. When, in 1947, I returned to live in the East it was wonderful to once again attend the meeting. In 1948 we saw changes, noteably more sophisticated optics and mountings. Albert G. Ingalls presented the first amateur-made Maksutov-type telescope (by G. Camilli of Pittsfield, Massachusetts) — an 8-inch Newtonian operating at f/4 — in the October 1947 *Scientific American*.

Stanley Brouwer, a former amateur turned professional during the war, displayed a photographic Schmidt camera in the early 50s, and Henry Paul demonstrated his temperature-stabilized f/1 photographic Schmidt at a meeting. Meanwhile, war surplus optics enabled amateurs to buy cheap but good eyepieces and aerial lenses for astrophotography.

In 1956, John F. Gregory displayed and presented a paper on his 5-inch f/15 Cassegrainian Maksutov — bringing advanced amateur telescopes within the reach of nearly everyone. Allan Mackintosh formed the Maksutov Club. His *Circulars* distributed monthly — along with *Sky and Telescope* which also ran many articles on advanced optical fabrication over the next several years — assisted those who attempted the challenge of the Maksutov telescope.

The 1950s also saw a proliferation of commercial companies. Those wishing to purchase a telescope soon had many sources from which to make a choice. But they didn't always last. The situation was even more obvious in the 1960s — with some firms lasting less than a year before their ads disappeared forever. Producing telescopes is not a basement-type operation — and failure to meet delivery times can quickly send a company out of business.

The first mass-produced Schmidt-Cassegrainian telescope was offered in January 1964 by a company whose name was soon to be known worldwide for Schmidt optical systems at a low cost, Celestron. Their first ad for Celestrons appeared in May 1964. They offered a 22-inch instrument which was soon followed by 10 and 16-inch telescopes. Their biggest seller, which appeared in June 1970, was an 8-inch Schmidt-Cassegrainian with mounting for $850. This telescope is, without a doubt, the biggest selling instrument in the history of astronomy. Today their success has several similar instruments in competition.

Just as mass production techniques made the Schmidt practical at a low cost, so were those methods soon applied to lowering costs of other finished optics. For those who either did not want to make their own or were too impatient to spend the necessary time in construction of optics but wanted a telescope *now* for observing, Cassegrain systems, Dall-Kirkham, and some Ritchey-Chretiens were offered to the amateur. Compound telescopes were becoming ever more prevalent at observing parties.

However, the size of instruments used by the amateur was still averaging about 8 inches. If an amateur owned, either by buying or making the optics, a 12-inch or larger telescope, he was considered to have a "huge" piece of equipment.

Electronics became more widespread in the field. In particular, for control of clock drives, it was no longer necessary to have exactly a sidereal time rate. A solar drive rate was sufficient — the drive control allowed you to vary the rate to cover not only stars but the Moon and planets as well. Photoelectric observations of variable stars and special objects by the amateur were becoming common. New clubs were formed to encourage these studies by the amateur.

During all this increase in small-aperture commercial telescope manufacture, a quiet revolution took place in the San Francisco area. Local amateurs, under the guidance of John Dobson, were fabricating large aperture, thin mirrors slung in special mounts. The sacred 1:6 thickness to diameter ratio for mirror blanks was ignored — and blanks less than 2" thick by 16 or more inches in diameter were figured into fine telescope mirrors! The simple alt-azimuth mount was an important part of the revolution; named the Dobsonian in honor of the designer, it employed simple Formica surfaces and Teflon bearings. These move, when properly made, with a smooth, but positive, tracking motion — and this motion is what makes this form quite acceptable on large instruments. I remember how impressed I was with the 22-inch instrument John Dobson brought to the Riverside Conference in 1971 — though bad seeing prevented viewing with it at the evening sessions.

Now I'd like to tell you about 1982, my 45th year of attending TM meetings. It sure was different than my first in 1937! In order, the first was the Texas Star Party, May 26-30th at Fort Davis, Texas. Although it really wasn't planned as a telescope meeting but more as a meeting for observers, they still brought their instruments to view in the dark Texas skies. The attendance was 440, plus 150 telescopes were scattered around the grounds of the meeting.

As a dedicated telescope maker, I was amazed. With all those instruments there, only about 10% were homebuilt! One field was just a mass of orange — Celestrons from 90mm to 14-inch in size with several carrying piggyback 5-inch Schmidt cameras for photography during the morning hours after the Moon set. The contrast to that Stellafane 1937 was like, well, day and night. And among the few instruments there that were not commercially-made or made with commercial optics, I found a second disappointment. When I checked for optical quality, few passed the test — that most basic test on star images in and out of focus. Quality was often passable but not excellent — definitely a disappointing result.

A second meeting in Peoria in July provided a better atmosphere for the hobby of telescope making with the majority of exhibited instruments amateur-made. Unfortunately circumstances prevented my making any evaluation of their optics.

In Peoria again there was an outstanding difference in the meeting from 1937 — commercial exhibits. Where there had been none in 1937, in 1982 an entire room full of instruments and accessories was available for examination by delegates to the meeting.

The final 1982 meeting was AstroFest 1982 at Kankakee, Illinois from September 24 to 26. This is billed as a telescope makers meeting — and in spite of the threat of bad weather (which for once was right), a good number of amateurs came out. I was happy, though. Most of the instruments were homemade, either completely so or homebuilt to house commercial optics. The number of completely commercial-made instruments was small (and more than one speaker mentioned faults of the commercial instruments). Many fine and interesting ideas were presented for examination and approval.

What are the important differences in meetings today relative to yesteryear? After you cover the use of catadioptric designs, the obvious answer is aperture! At all these meetings in 1982, sizes over 12½ inches were common in telescopes — many of them on Dobsonian mountings. Large aperture telescope are no longer unattainable — or unhandy to operate — so the rush to own these giants has been on for several years now and is growing daily. Deep-sky observing has taken over from lunar and planetary viewing as the observer probes deeper and deeper into the depths of space with his telescope.

How does an old timer like myself view this revolution and new breed of telescope maker and observer? With mixed emotions at least! Has the hobby of telescope making benefited overall? Personally I cannot say it has. Many people today point out "it is cheaper to buy a mirror than make one due to the high cost of materials and coatings." I know of two instances where former instructors of classes in telescope making closed them down on this premise!

For many years the telescope maker had the incentive that in this "poor man's hobby" he could make an instrument many times cheaper than an equivalent instrument could be purchased. However, as time went by and kit costs rose, this principle was replaced by the challenge and thrill of doing it oneself. In no other hobby can one point to a finished product and say, "It is accurate to within five millionths of an inch, and I made it myself!" The experience and knowledge gained in mirror making — especially for youngsters — are important to a complete understanding of telescope operation and optics, and invaluable to anyone who does make a mirror.

Incidentally, today there are a number of classes which advertise "telescope making" — but really they are not. No optics are ground, polished, and tested; instead purchased optics and parts are put together under an instructor. In honor of the thousands of amateurs who have made their mirrors, thus really "made telescopes," and in honor of the memories of the giants of the past — Porter, Ingalls, Everest, Paul, and others too numerous to mention — let's be honest with ourselves. We encourage these classes, but let's change the course name to reflect its true nature. Such courses are properly called "telescope assembly" classes.

The interest in observing deep-sky objects is new and even five years ago was limited to Messier objects only. With the large instruments now in use, many objects found in the *New General Catalogue* and the Herschel List are being sought by observers. Perhaps many think that due to spacecraft probing of planetary surfaces, such amateur observations are not valuable to the astronomer. Nothing of the sort: the wide view of planets from Earth telescopes gives valuable information to the scientist and is still a worthwhile project for the observer. However, the special short-focus large-aperture telescopes are not ideal for this; high power oculars or added optics (such as Barlow lenses) are needed to give a working image size and the glare from the brighter planets makes viewing faint detail difficult.

The catadioptric revolution has had its fallout, too. Ten years ago it became fashionable to own a Schmidt-Cassegrainian telescope — so for many the simple Newtonian fell into disgrace. So, too, the aperture revolution has seduced the beginner, in particular, into believing that the only way to go is bigger. Well, nothing could be further from the truth. You must learn to operate and train your eye to properly use a telescope — and nowadays many beginners become discouraged before they learn the limitations and proper operation of a large instrument. You must crawl before you can walk or run. Just reading the ads for used telescopes reveals the problem of "too much too soon" with many ads offering "hardly used" catadioptrics or large aperture telescopes.

To further complicate the problem for the new amateur astronomer, inflation hit the telescope field like everything else. Each year it is an embarrassment near Christmas time having to tell people that the "poor man's telescope" no longer exists — and that to satisfy the whim of their child requires an investment of several hundred dollars for a simple 6-inch Newtonian and well over a thousand for a tripod-mounted catadioptric. During the Depression there was a saying, "What This Country Needs Is a Good 5¢ Cigar!" I'd like to add for the 1980s: "What This Country Needs Is a Good $150 Telescope!"

But fortunately, and somewhat surprisingly, the hobby of telescope making is still alive and healthy today. Last year some 2,000 delegates went to Stellafane and over 1,100 appeared at the Riverside Conference. One feature of note at the meeting was the appearance of refractors, an instrument seldom seen at such meetings. With the advent of fluorite and special glass melts, sensibly color-free lenses for astronomical viewing are now coming into their own. Although most are commercial, such telescopes can equal the performance of TCTs and unobstructed-type reflecting systems; however, cost is still a big problem for the average amateur.

What does the future hold? Hopefully some new and exciting developments in optical systems, such as the Maksutov and Schmidt-Cassegrainian of the past; improved accessories in mountings (the Poncet, for example) and viewing apparatus, in particular the use of image tubes to increase the light gathering capabilites of instruments. Intermediate and advanced amateurs will adopt equipment that uses electronics to view and record images and variations in brightness of celestial objects. Home computers will find themselves integrated into the telescope operating system, too.

In spite of some of the negative aspects mentioned earlier, telescope making as a hobby will continue to advance and grow around the world. I personally feel very happy that I can look back and remember the early years of telescope making and the privilege of meeting and speaking with the giants at Stellafane 45 years ago. It is particularly gratifying to be able to continue to help the amateur through TELESCOPE MAKING and the staff of the AstroMedia Corporation.

Years ago it was common to say, when you had finished a telescope, optics and mount, that you received an honorary degree of T.N. ("Telescope Nut"). It is with pride that I sign off in recognition of this.

— Robert E. Cox, T.N.

■

GLASS & GRIT
Seen with the Scanning Electron Microscope

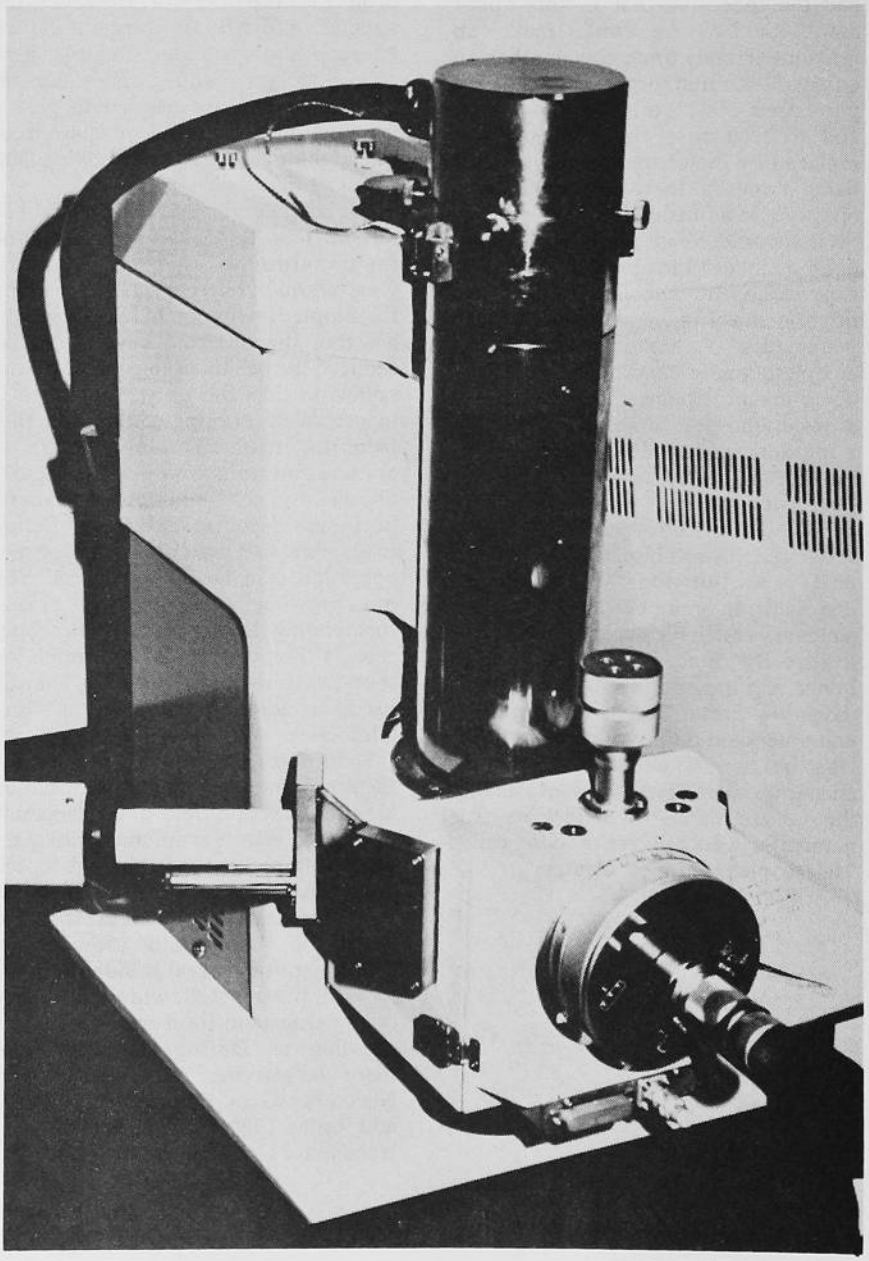
Did you ever wonder what really happens when your grind glass against glass? Texereau shows grinding pits schematically as chonchoidal fractures, and the ATM series shows them as little craters (apologies to Unk, and all that!) — but what's *really* going on down there between the mirror and the tool? I got curious and decided to find out.

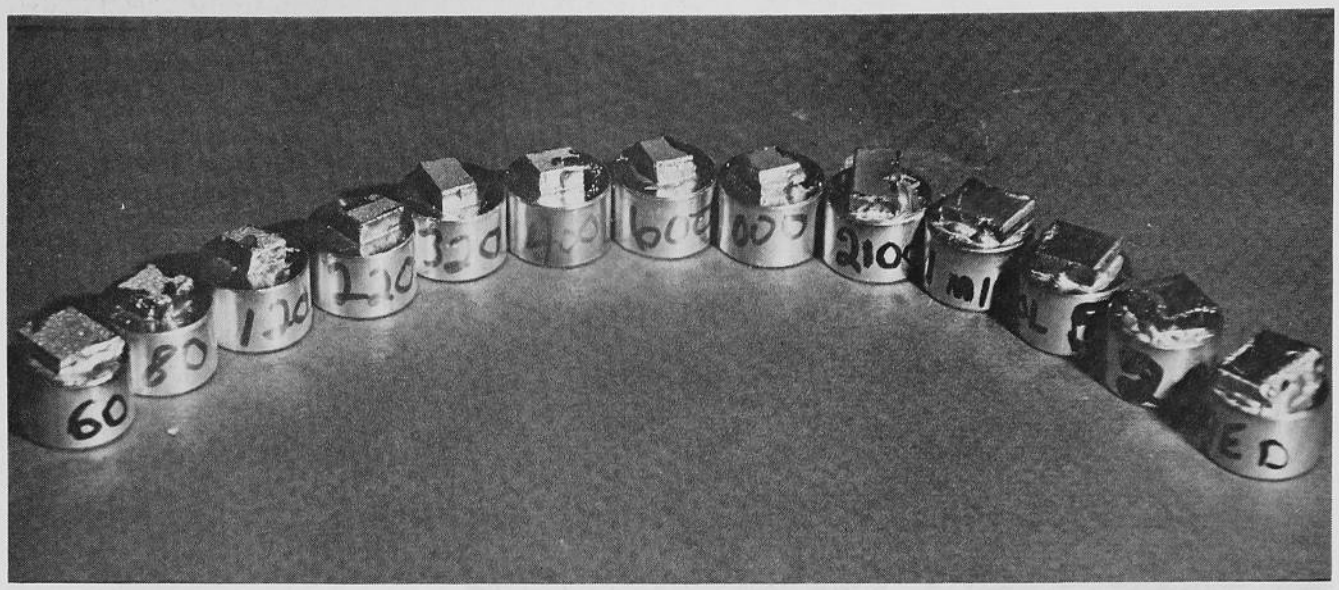
Glass and tiny grains of abrasive are too small for the conventional light microscope (not to mention the problems involved in looking at the surface of a piece of glass), so I decided to examine some samples with the electron microscope available to me through the good graces of my employer, Macalester College.

Let me fill in some details as to the procedure of obtaining these scanning electron microscope pictures and what they illustrate. The procedure in preparing glass samples was governed by the rather small size of the sample required for the vacuum chamber of the microscope.

I ground individual samples of glass on a larger slab of glass with each of the commonly used grades of telescope makers' grit, from #60 silicon carbide to #1000 aluminum oxide. Compare the ground surfaces with the samples of grit that made them.

After grinding the 2-inch-square samples of thin plate glass with the varied grades of grit, ¼-inch squares were cut out and attached to the top of individual aluminum "pucks" with a silver-bearing cement. These "pucks" are used as the carrier device to place the sample to be scanned into the best position. The silver cement guarantees electrical continuity with the electron beam. After the cement dried, each of the samples was placed in a special vacuum system designed to deposit an extremely thin layer of pure gold atoms over the top of the sample, connecting





it electrically and equally with the silver cement and the aluminum puck. This layer in no way interferes with the detail being sought, being only a thin sputtered coating — in fact, the layer is so thin that visual inspection revealed a barely detectable gold coloring after this procedure.

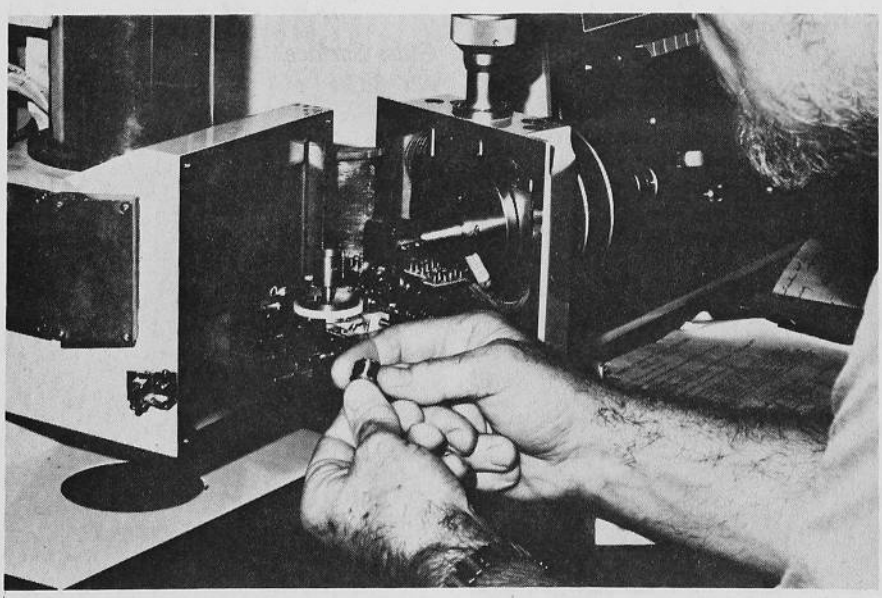
There are external manipulators which allow the sample's position to be controlled from outside the vacuum chamber — and we rotated the sample in a manner that placed its face at a 45° angle to the scanning beam direction. This gives a better depth perspective via "shadowing." All the samples were shot with this angle.

Although the instrument is capable of magnifications exceeding 100,000x, the subject matter of this investigation did not warrant such a degree of magnification. It was necessary, we felt, to stick to one standard magnification for all the samples to keep the proper perspective in the final display of surface features and later, the grit itself. Experimentation showed best rendering of detail on the glass surface was obtained with a magnification of 750x.

There is a special procedure in operating the vacuum mechanism into which the sample is inserted. The electron beam source employs a heated filament also in the vacuum which prevents it from oxidizing instantly. One must be careful — opening the chamber too soon after the photos are taken can destroy the filament very quickly.

But first things first. You see the sample displayed on a TV screen. There are actually two screens: one arranged for visual inspection and the second is seen by the camera making a permanent record of the subject.

There is a bit of fussy focusing and adjustment of brightness and contrast controls to match the properties of the Polaroid-type PN 55 film. I used this film because immediate development means I knew what I'd gotten, and it produces a fine 4 x 5 negative which can be treated for permanency. I was pleasantly surprised to see nearly a total absence of the otherwise familiar raster pattern which a close examination of your home TV screen presents. None of this destruction of finest detail takes place with the scanning electron microscope.



Several of the glass samples were fine-ground with #2100 grit. One was left that way for inspection as to the degree of coarseness it left on the glass surface. One was polished on a flat pitch lap, imprinted with the nylon mesh we always employ on our larger pitch laps here at Macalester. Using cerium oxide polishing compound, the first sample was polished 1 minute, the second sample for 2 minutes and the third sample for 5 minutes. These are certainly not long intervals — but what they do to erase the pits is simply wonderful.

In fact, I certainly believe it will surprise many amateur telescope makers to see the efficiency with which cerium oxide polishes glass. (I know there are good souls who will never change over from the classical iron oxide rouge. They can be recognized by their stained fingers and clothes and the many hours of stooped-over labor getting their polished surfaces finished. To each his own.) But at least I have visual evidence as to the efficiency of cerium oxide which reinforces my continued use of the stuff.

The micron scale on the prints is automatically registered on the film. You will see by that scale that many bits of debris smaller than 0.5 micron, the wavelength of yellow light, show up. Not only are they seen, but they are seen clearly and sharply outlined. When

Original Glass Surface

it came time to study the character of the grit itself, sample pucks of material were made of grades #80 silicon carbide (SiC), #240 SiC, and #240 aluminum oxide.

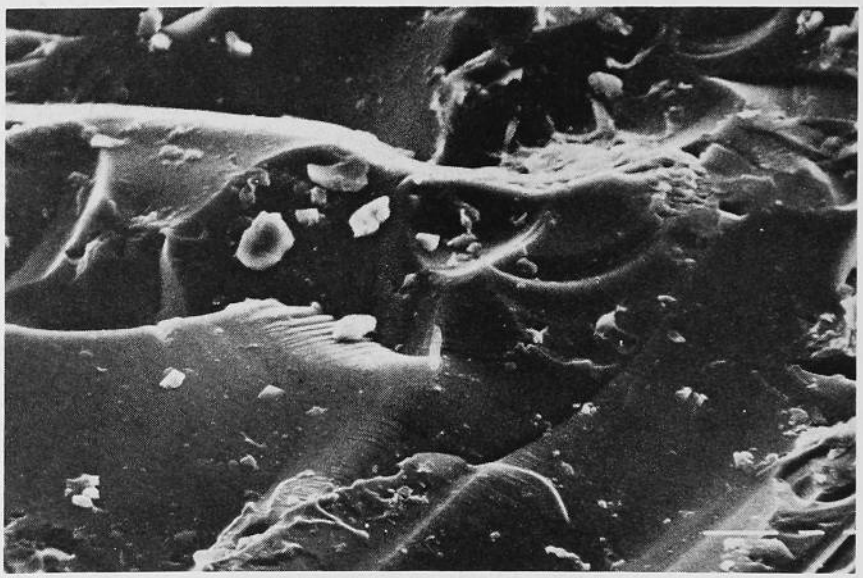
While all the photos of glass are made under equal magnification, the finer grades of grit were examined at 1500x to show better the structural detail in their shapes. The coarse grades were found to render the best detail at magnifications of only 75x, rather than the 750x the pictures of the glass itself were rendered in. When I tried 750x with the #80 grade, I was surprised to find that I couldn't get more than two or three particles into the frame. The #1000 shown is aluminum oxide. Both the cerium oxide and rouge were magnified 1500x. All the prints sent to TM were full-frame from the 4 x 5 negatives, so the linear magnifications were doubled on those prints but halved again in the reproductions.

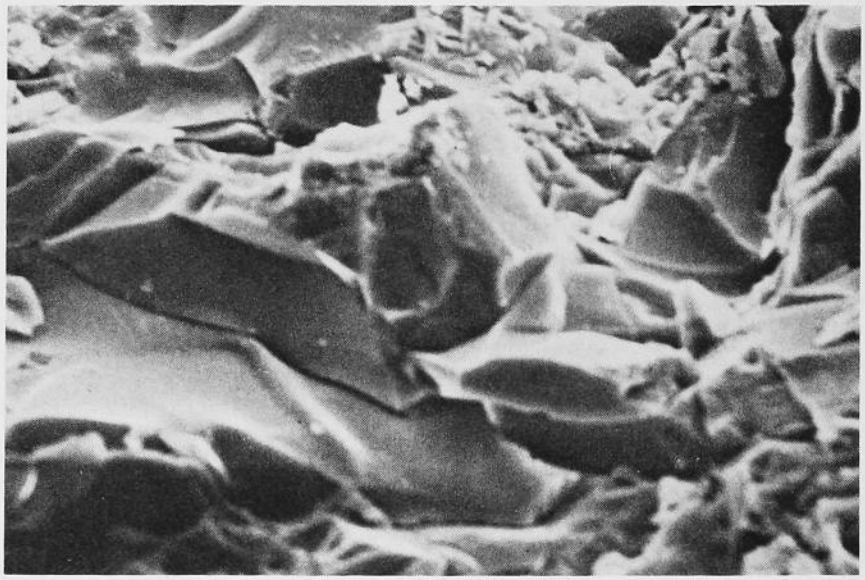
I'd like to credit the Macalaster College Biology Department for giving permission to use their scanning electron microscope. Particular thanks goes to Dr. Russell Whitehead for his generous expenditure of time and energy in showing me the intricacies of operating the microscope.

Sherman W. Schultz, Jr.
Observatory-Planetarium
Macalester College
Saint Paul, MN 55105

■

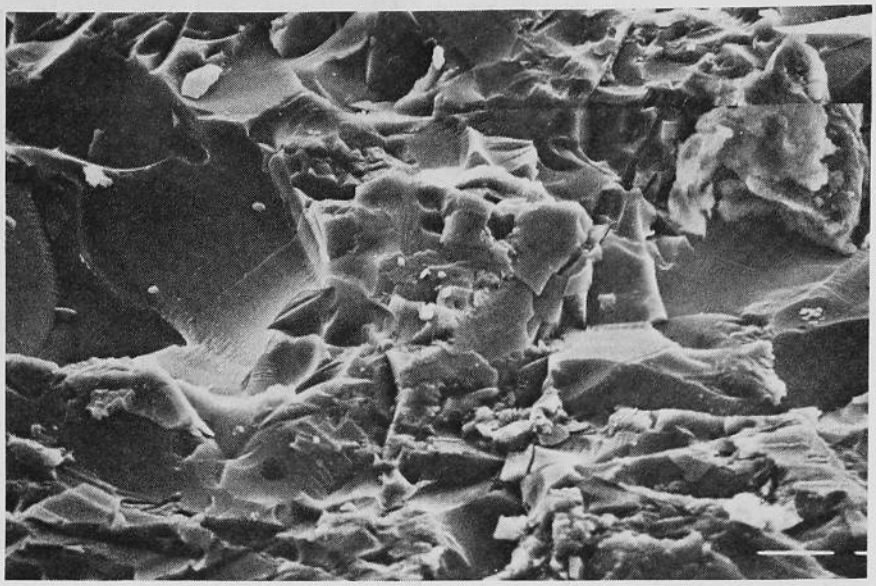
Glass Surface
#60 SiC
75x

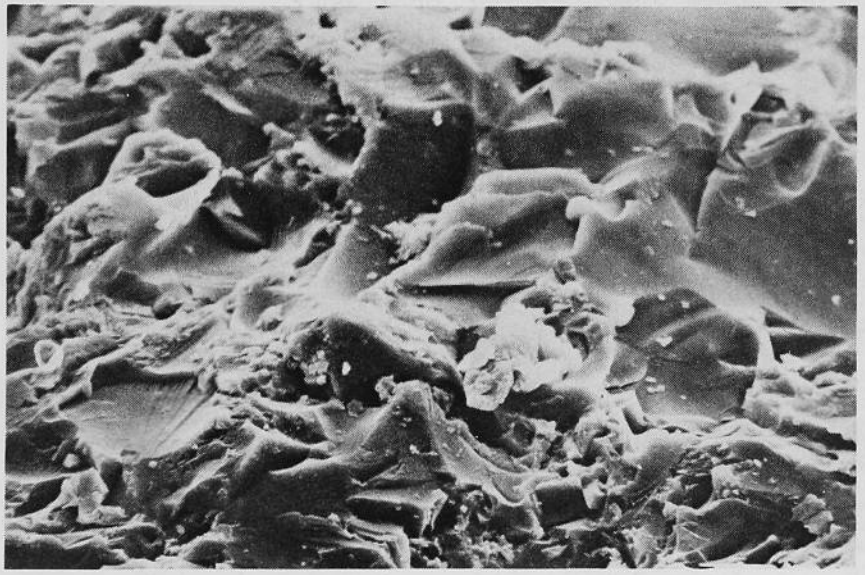




Glass Surface
#80 SiC
75x

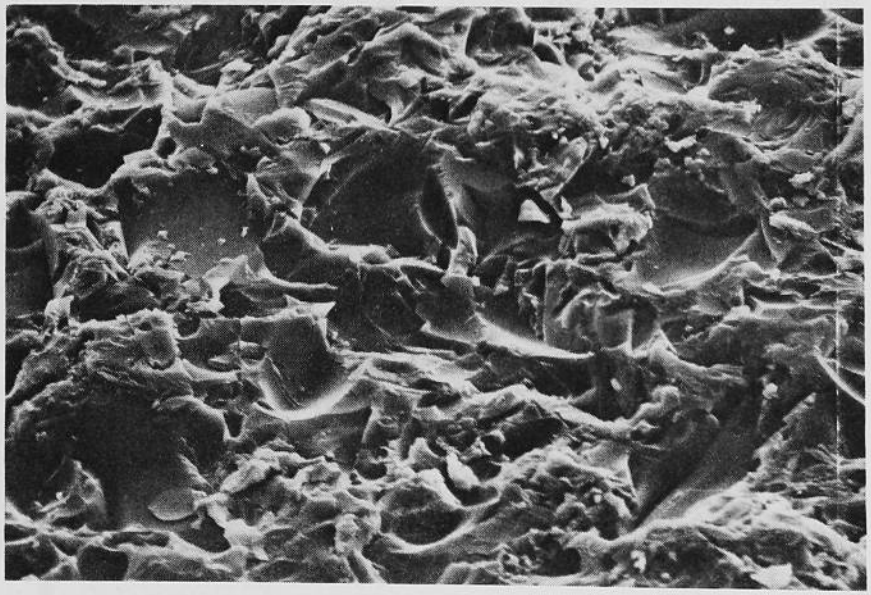
Glass Surface
#120 SiC
75x



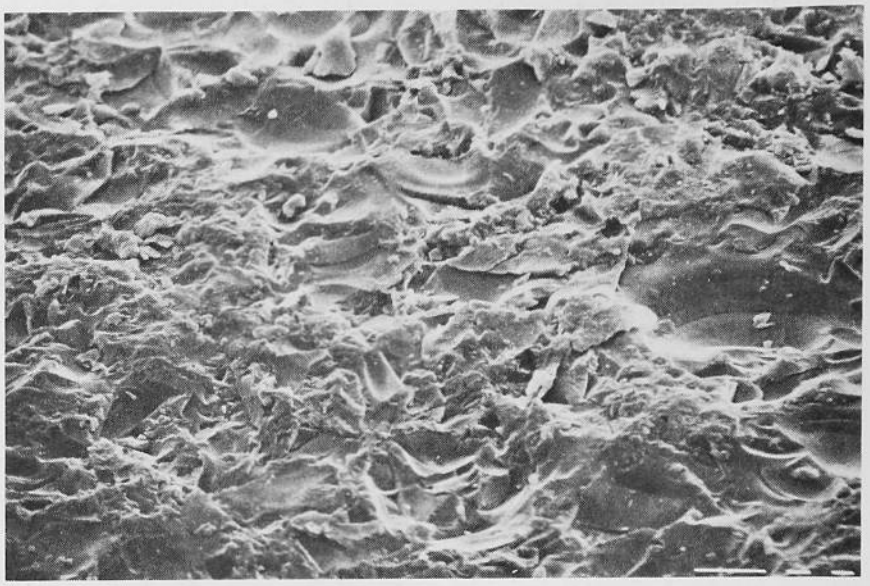


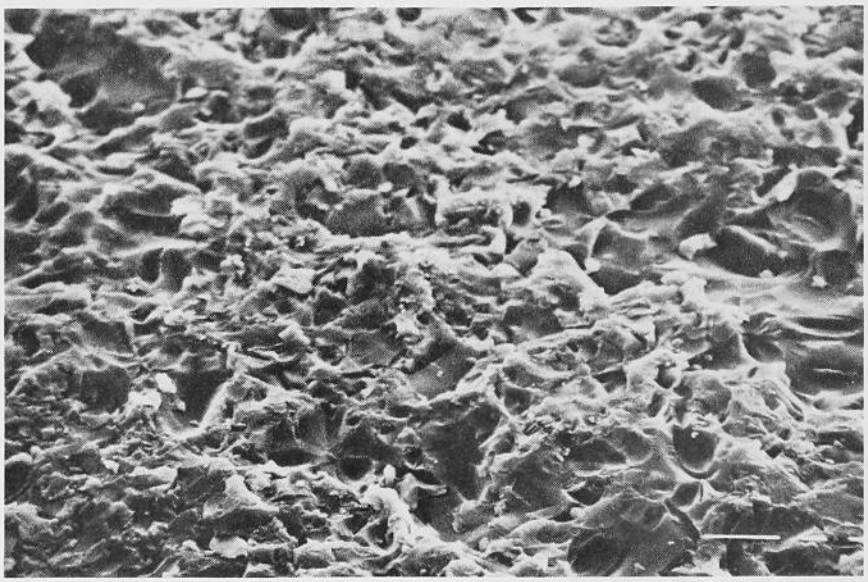
Glass Surface
#220 SiC
75x

Glass Surface
#320 SiC
75x



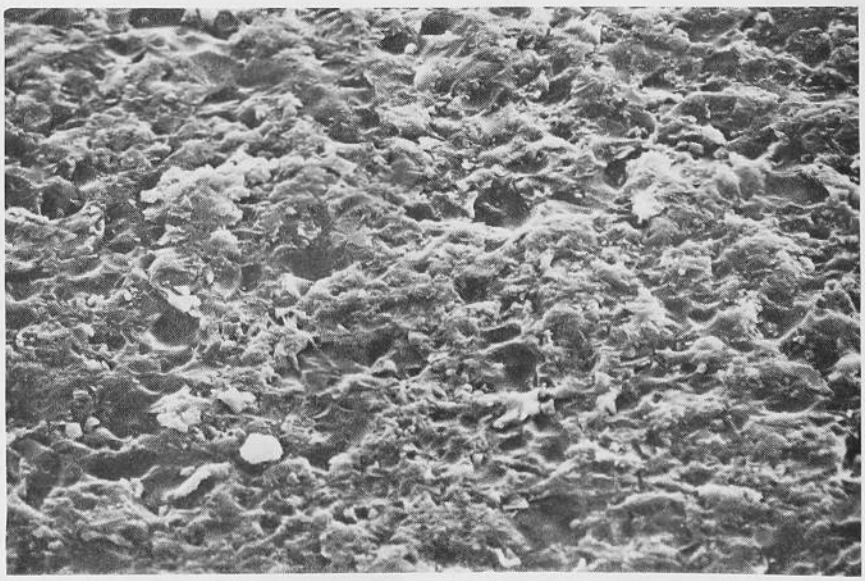
Glass Surface
#400 Al_2O_3
75x

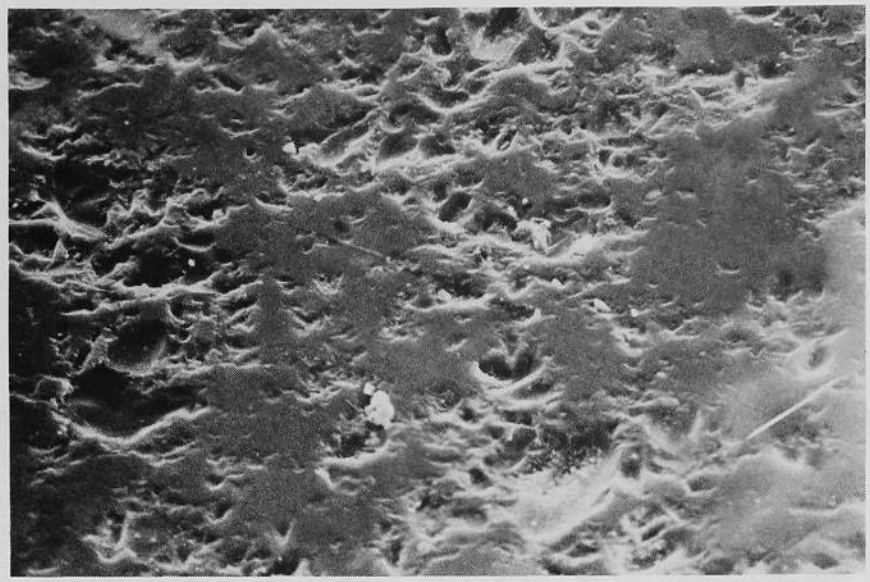




Glass Surface
#600 SiC
75x

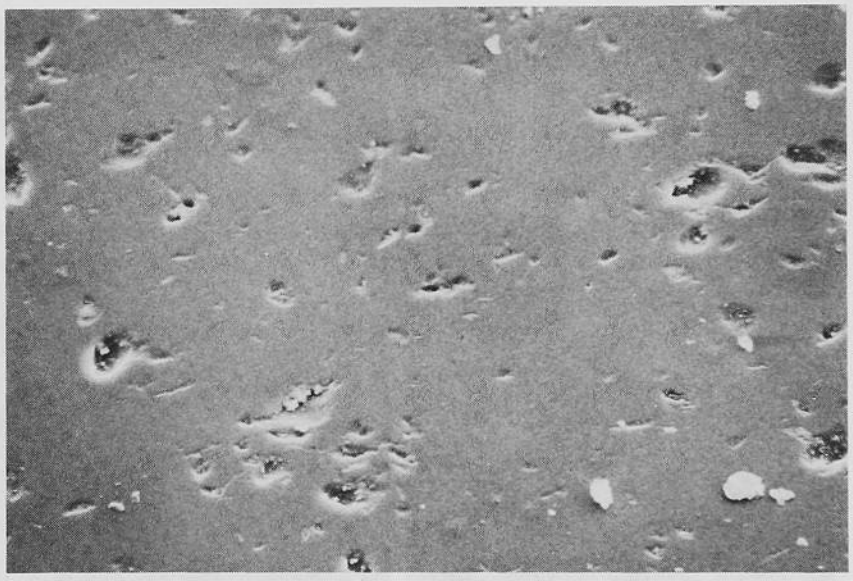
Glass Surface
#1000 Al_2O_3
75x





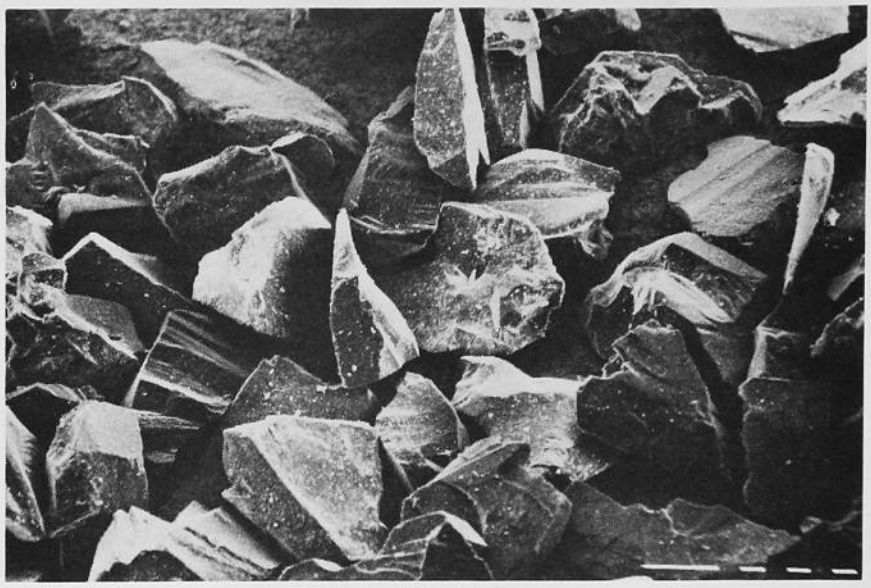
Glass Surface
1 min. polishing
with CeO_2
75x

Glass Surface
2 mins. polishing
with CeO_2
75x



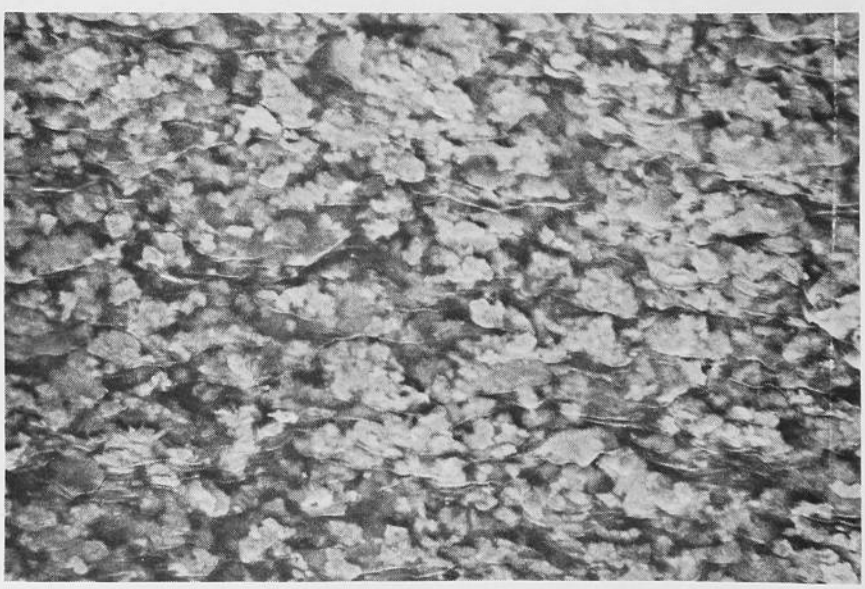
Glass Surface
5 mins. polishing
with CeO_2
75x

Abrasive
#80 SiC
75x

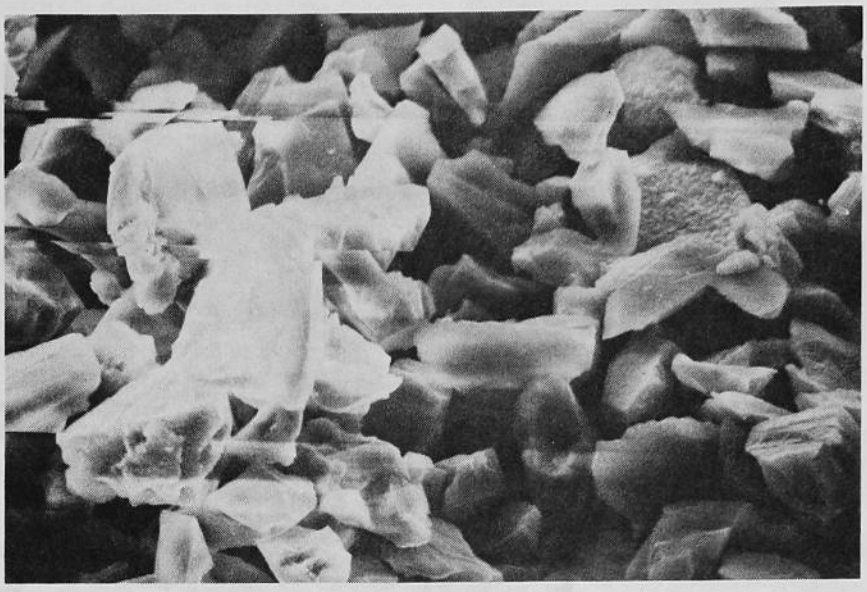


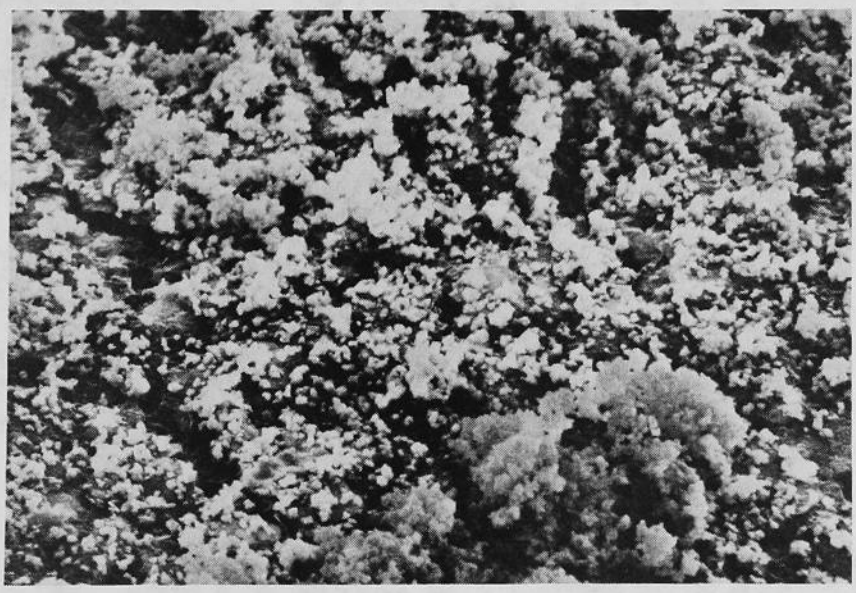
Abrasives
left: #240 Al_2O_3
right: #240 SiC
75x

Abrasive
#2100 Al_2O_3
75x



Abrasive
#1000 Al_2O_3
1500x





Polisher
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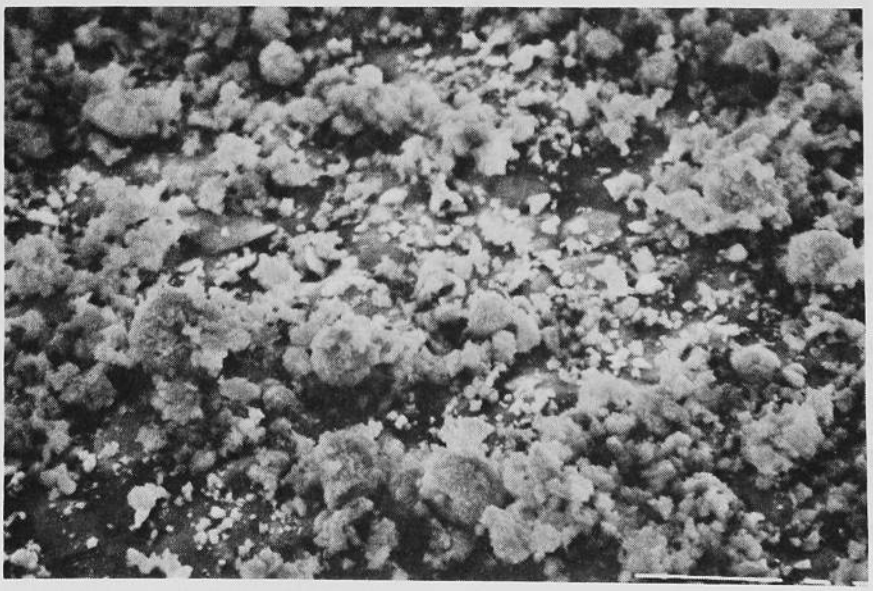


RIVERSIDE 1983

Early this year I was elated by the news that Richard would be eclipse chasing, so I would "have to" represent TM at the Riverside Telescope Makers Conference this year at Big Bear. It had been much too long — since 1980 — since I last visited Camp Oakes high in the San Bernardino Mountains. I looked forward to renewing old acquaintances and making new friends in the telescope making fraternity. How slowly time passed 'til May 27th arrived and I went to the airport. California bound at last!

But things started off badly in St. Louis. My scheduled 9:15 a.m. departure arrived at 9:24, so it wasn't until 10:15 that our wheels finally left ground, after a power run of some 38 seconds (LCD stop watch functions are fun!) up through a cloud bank and westward ho. The flight would be nothing new, as in the past 22 years — either for my company or on vacation — I had made at least 20 similar flights.

Still, I always like a window seat. There's a lot to see. For example, when we're near large cities and low enough to try, it's fun to spot golf courses. You can determine the plane's height on the basis of whether or not you can see cars on the highways below. I have found that using heights given by the captain, I can see cars on highways under 28,000 feet, but over that they are invisible. Given that a car length is 20 feet, from a height of 28,000 feet, the angular subtense of the car would be about 2.5 minutes of arc! The average person's acuity of vision is about 2 arc-minutes and allowing for contrast loss through haze, the slightly larger figure is a reasonable figure. It is also useful to determine when passing through 28,000 feet on the way to higher altitudes. Anyhow, we flew at 35,000 feet and it was not possible to see cars below.

The flight was uneventful until, taking a glance out the window,

something I had never seen in all my westward flights became visible. Could it be that there was the most famous astronomical sight to be seen in the southwest? Wait, to the west was a dark winding crack in the desert, one of the many canyons to be found in the area, but this one was different: it was Canyon Diablo, some 4 to 5 miles west of this important object I was seeing from the air for the first time. Even at a slant range through haze of more than 10 miles, Meteor Crater was a breathtaking sight with a depth of about 600 feet, a rim 130 feet above the desert, and a diameter of some 4,200 feet. It was thrilling to imagine the scene some 50,000 year ago as a huge flaming mass of iron streaked across the sky plunging into the Earth to bury itself beneath the south rim of the excavation. To any living creature around, this would truly seem the end of the world! It was also unfortunate that on this plane the captain did not announce points of interest, so no one else on the right side of the plane probably noticed this amazing object.

Ground foul-ups continued upon arrival. My car reservation had been lost and it took over an hour before I got my compact and started for Camp Oakes. Unfortunately, by then it was almost 1:30 p.m. — and it appeared that just about everyone had taken off work early and was headed toward the mountains. To cover a distance of slightly over 100 miles from airport to Camp Oakes, it took 3½ hours on the road. I arrived at the registration tent at 5 p.m.

By the time I was settled in the bunk house, it was 5:30 and time for dinner. Although I was dying to get up to the telescope field to see the instruments, discretion is the better part of valor at mealtimes, so to avoid a long wait in line, it was best to eat first. One thing almost 50 years of knowing amateurs has taught me is that although their first love may be astronomic, the second is always gastronomic.

Finally after dinner it was out to the field for 1½ hours of telescopes. However, it was first necessary to work past the commercial exhibit row, which was along the west side of the path — and a large display it was. First I greeted Norm Sperling who had a large collection of books (and lots of back issues of *Sky & Telescope*, in particular) for sale. One had the opportunity here to get missing issues to complete a home collection.

Alongside Sperling was an old friend, Dick Nelson, who was once again offering an amazing collection of war surplus optics and items off the tailgate of his station wagon. I was glad that I had flown to the meetings since it kept me from spending money on some of the interesting items along this row.

The Coulter Optical display had Dobsonian Odyssey instruments from a 10-inch to the 17-inch out for examination, but due to the Full Moon in the sky, this year they'd decided not to bring the 29-inch telescope down.

Many vendors brought telescope parts or accessories that were slightly damaged or display items from their stores. Those sales were brisk. Celestron had some primary mirror blanks for just a few dollars that had slight edge chips or imperfections, including some 14-inch molded blanks.

By the time I had greeted old friends by these exhibits and examined the items, it was too dark to take pictures and the 7:30 evening program was starting.

However, I managed to examine the largest instrument displayed, a 29-inch Coulter mirror purchased by David Shipman of the Santa Barbara Astronomy Club and put on a modified Dobsonian mount. The azimuth movement was done with a set of wheels rotating on a flat lower surface, but the altitude was conventional. It was in a square box: massive in appearance and operation. There were two 24-inch telescopes also on display, but with their folded Cassegrainian designs, the ease of handling made the huge Newtonian seem awkward indeed. What you have to endure for deep-sky observing by way of convenience in handling in large aperture telescopes was brought home forcefully by the 29-inch scope.

The 29-inch mirror was one brought by Jim Jacobson last year, but now it had been finished to specs before being sold to Mr. Shipman. The 130" focal length of the f/4.5 instrument plus the mounting raised the eyepiece far above the ground. Observing the Hercules cluster later that evening far up at the top of the supplied ladder was a nerve-racking experience — especially when movement of the object and repositioning of the instrument left you hanging off the ladder at an angle.

I climbed down and had the ladder reset closer to the eyepiece before I would use it. The heavy weight of the unit made azimuth movement stiff, so one of the club members sat at the bottom of the scope and when the object moved off-center, repositioned it by sighting through a finder and crosshairs. This was fine — it left me with two hands to hold on to the ladder.

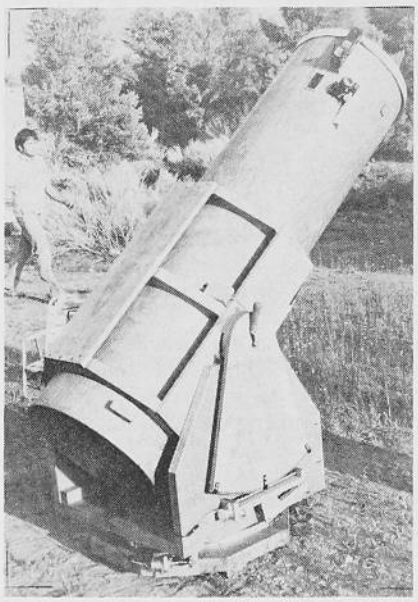
However, the seeing was poor, so images in the telescope were soft and the background bright due to the Full Moon now in the sky. One advantage of the Full Moon is there was no need for a flashlight to wander around the telescope field at night — but the disadvantage of the Full Moon was deep-sky viewing was impossible. Since the bad seeing made viewing of the planets and double stars poor, I decided that rather than spend time among the telescopes that would produce no positive results, I returned to the main meeting hall to meet friends and delegates and exchange information on telescopes and telescope making. There I found my good friend Dick Buchroeder who decided to come early and enjoy the full weekend even though his paper wasn't scheduled until Sunday afternoon. Dick was interested in seeing

This year's biggest telescope, a 29" f/4.5 Newtonian using a Coulter mirror. The altitude bearing was conventional Dobsonian construction, but it had wheels for the azimuth motion. Although the tube says, "Santa Barbara Astronomy Club," the telescope was made by member David Shipman of Goleta, Calif.

Big Bear so we arranged to skip breakfast and drive into town and get stomach fuel to start the day there. As it was approaching midnight, we retired with a 7 a.m. breakfast date.

Big Bear is a quaint little town. We found a home bakery that supplied us with several goodies to munch on at odd hours when we got hungry. Upon returning we decided to skip the morning paper session in order to see and photograph the telescopes put on display in the telescope field and surrounding areas. After once again passing by the commercial row with its many wonderful bargins, we were surrounded by amateur telescopes. The first to catch the eye — after the 29-inch — was a beautiful wooden Dobsonian by Dan Raether and Carl Blue which in 1982 had been an award winner. This year they had reworked the mounting for electric slow motions to both axes. The altitude was a tangent arm arrangement with a springloaded quick reset using a curved bolt gear. The azimuth was a continuous wire drive. Between the two motions, one could continually shift the telescope with a minimum of vibration to hold an object in view. In my estimation they also deserved another award (but did not receive one) as the drive system was by far the most ingenious device exhibited on a Dobsonian this year.

In sharp contrast to the electric slow motions was the Dobsonian of Rick Schaffer. It won an award in 1981 (and was described in TM#6). The telescope



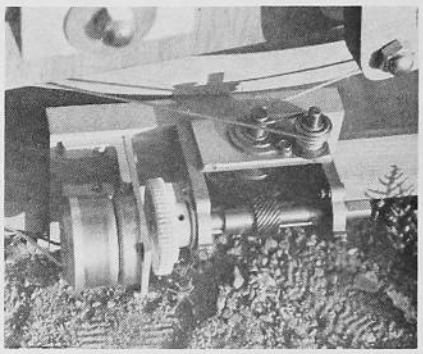
A beautiful wooden Dobsonian-mounted telescope that received an award in 1982, now has electric drives on both axes for tracking without having to touch the instrument manually. The altitude is tangent-arm spring loaded for quick reset, while the azimuth is a continuous wire drive. Note how the azimuth drive employs a cable wrapped around a large drive wheel. The altitude drive is a curved bolt.

uses spring-loaded wooden arms on the side of its tube to track objects. For simplicity and convenience of operation it's hard to beat — readers should look up this article and consider applying it.

I could not help notice and admire the colorful tube of Jeff Carmack who covered the outside of his Dobsonian with paintings of celestial scenes done by him, his girlfriend, and G.Moore. A 4-inch RFT with solar filter for daytime Sun viewing was added to the commercial instrument as was an accessory eyepiece rack.

Up on the slope beyond the Carmack instrument was the 10-inch f/7 Newtonian made by Randall Wilcox. The mirror was a Coulter optic, but he did all the mounting and fabrication of the mount. On the far end of the declination axis is a 6-inch f/4 to f/16 instrument ground and figured by Randall. The mount was cut out and welded together and a Byers 8" drive added in R.A. but Randall added a homemade tangent arm declination unit. The instrument is used for astrophotography and (when they are around) for recording comets.

In 1982, Keith Lawson of Lancaster brought his plywood astrographic mounting, and this year returned with a 4-inch commercial objective on an excellent equatorial mounting that



earned him one of this year's awards for workmanship. Keith is a machinist by trade and applied his skills in the fabrication of his instrument.

Wood is a pretty item when used properly and the instrument of Dave Pitou of Sacramento is a fine example of workmanship in this material. The 12½" f/5 primary was refigured by Cave, while the 6-inch Maksutov was by Sky Research and the 5-inch refractor was a $20 lens bought at a former Riverside meeting. No black and white photo can do justice to the beauty of the Honduran mahogany tube and its finish. Everything on the telescope, except the optics, was made by Mr. Pitou.

Mr. Edward H. Pasko of Santa Maria, Calif. exhibited a 3-inch fixed eyepiece telescope of his design that earned him one of the 1983 awards for excellence. Two mirrors on rotating axes allow full sky viewing in a fixed eyepiece location. The flat that handles declination is solid and feeds the right ascension flat which has a central hole. Light from this latter flat is directed to the 3" paraboloid at the lower end of the central tube which then focuses the light through the hole to the eyepiece. Polar adjustment is unusual in that you put in a low-power

The Dobsonian made by Jeff Carmack. He reworked a commerical Dobsonian, adding his own 4" RFT, and adding a smaller 9x60 refractor finder. Paintings by himself, his girlfriend and G. Moore. Eyepieces are carried on side of mount. The RFT has full aperture solar filter on for daytime Sun viewing.

ocular and spin the polar axis while pointing the optics to Polaris. When Polaris makes a circle centered in the ocular, you have proper polar alignment! This type of design was used with a refracting lens in front of the first flat (and no hole in the second one) on Loewy's Equatorial Coude mount in 1883, and a picture of it can be found in Bell's *The Telescope* on page 432. The one disadvantage is that the three reflections, if regular aluminum is used, let only 68% of the light from an object reach the focal plane. Such an arrangement should have at least 94% reflective coatings so you would then receive 83% of the light energy. Of course, the hole in one mirror will affect the diffraction patterns like a central obstruction in a Newtonian so that you lose some of the high definition that a refractor ordinarily gives.

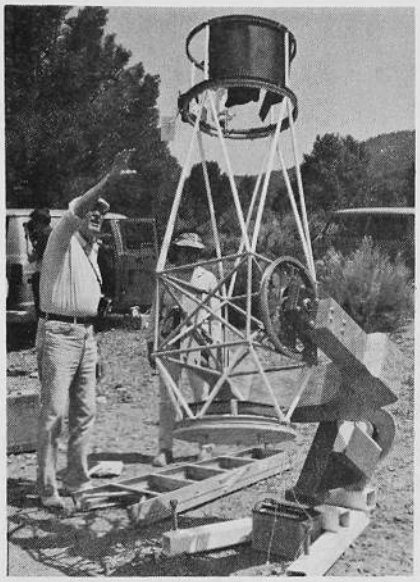
One of the dominating instruments on the field Saturday was the 24-inch "yellow giant" made by Roger Sanders of Atwater, Calif. Another award-winning telescope, it was the most unusual of those presented in that it applied the modern technology of aircraft-type composite construction. It was made from foam core hot-wired to shape and overlaid with various types of fibers, some glass but others graphite (Kevlar and boron can also be used). The whole unit, including the optics weighed only 205 pounds and was in three units that disassemble without tools. The primary mirror was shaped so it had a convex back with the center

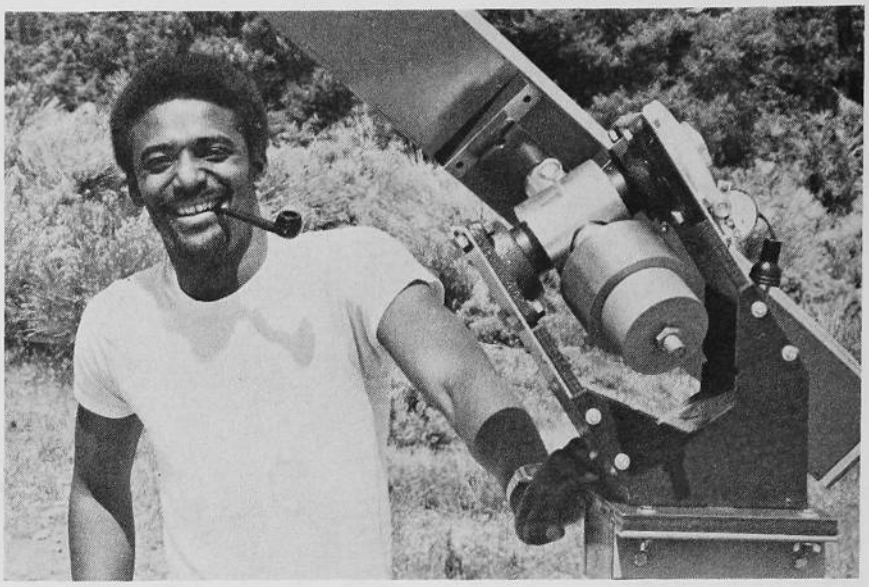
The 24" "yellow giant" made by Roger Sanders of Atwater uses new technology for aircraft-type composite construction. Foam core was hot-wire cut to shape, then overlaid with various types of fibers (some glass and some graphite, though Kevlar and boron could also be used). The whole unit, including optics, weighs 205 pounds! It's made in three pieces and disassembles without tools; parts are stainless steel, aluminum, brass, epoxy, bronze. There's nothing to rust. He ground the mirror, but Scott Optical in Fresno figured it to better than 1/10 wave. Drive is a 15:1 roller ratio in R.A., with a separate motor-driven indicator. It cannot be coupled to main axes since it removes for transportation and just drops into position in use.

retaining its original thickness but the edge being only about one inch thick. By supporting the large mirror at the center, no other supports are necessary and it retains its symmetry in all telescope positions. The mirror was ground by Sanders but figured to 1/10 wave by Scott Optical in Fresno. Stainless steel, aluminum, brass, epoxy, and bronze are used so there is nothing to rust on the telescope. The top of the tube rotates to bring the eyepiece to a comfortable viewing position. A special support system on the diagonal keeps the flat in alignment yet can easily be adjusted if necessary.

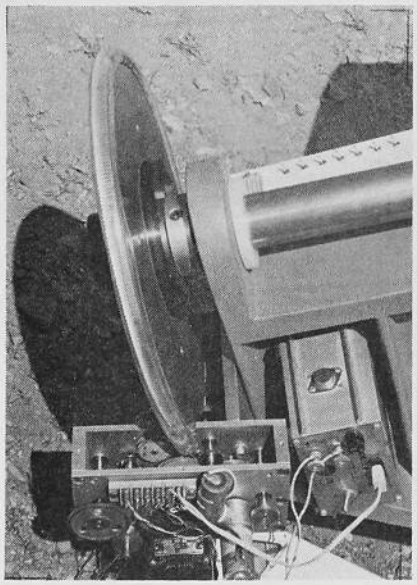
The polar axis and roller drive are arranged so the axle can be removed for transportation, and this presents a problem for the R.A. setting circle. It, therefore, has a separate motor drive and indicator.

Nearby was another award winner, the 12½-inch fork-mounted telecope of Reinhart K. Buchner of Westminster, Calif., that had a commercial optical





The award-winning refractor of Keith Lawson of Lancaster. The objective is commercial, but the tube and mount are homemade from scrap metal and wood. Lawson is a machinist by trade. An excellent job, and rightly so, it received an award Sunday night.



This close-up shows the drive on a 17½" fork-mounted telescope displayed by Derek Reynolds of Burbank.

system, but a mounting built entirely by Mr. Buchner. A nice approach was the built-in West-type drive control around the polar axis in the base of the mount.

Derek Reynolds exhibited a fine 17½" Newtonian on a fork mount made of welded electrical components and bicycle rims. The fork itself was laminated plywood with a maple veneer.

The smallest — and without question, the lightest — Dobsonian present was that of Patric Canan of Corvallis, Oregon. The 9.5-inch f/3.8 mirror of this RFT was homemade of ceramic materials and attracted a lot of interest and comment. The ceramic mirror was relatively new and therefore no information was available on its long-term stability and the effects of its surface structure. Mr. Canan also had a fine larger instrument that broke down for transportation and a Poncet base variation model that he will be writing up for TM later.

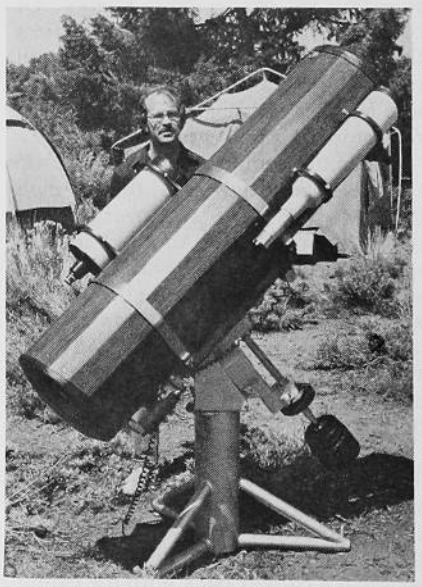
The laziest amateur present was Dave Wile who had an open-tube 90mm RFT war surplus f/5.6 lens suspended on a special tripod and rope support that allowed him to lie back and observe the sky. He also exhibited an 8-inch Newtonian that collapses into a box 18x12x12 for transportation, and instead of a conventional spider, had a "ring" type that was popular back in the 1950s and 60s. He said that he liked the lack of spikes on bright stars, but he was not eliminating the scattered light of a regular spider with this form of device, just spreading it all around the field where it was not as noticeable.

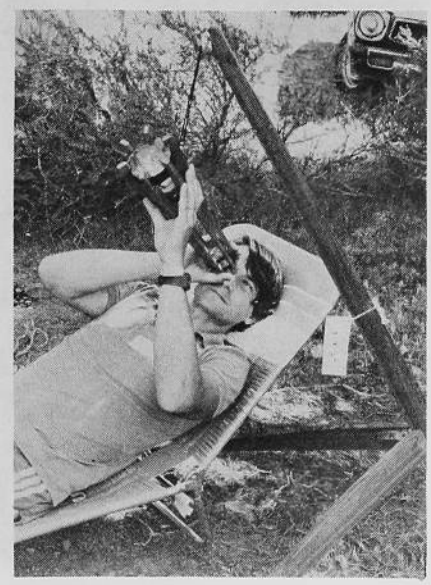
Late in the meetings a huge 24-inch telescope arrived to be set up down by the lake. In travel, the mirror end is horizontal on its trailer, and the viewing ladder is placed on it and the upper stage assembly of the tube on that. It was assembled on Sunday, but whenever I went back to it, no one was around to give information on the operation.

You seldom see a falling weight governor-controlled escapement for driving a telescope today, but near the 24-inch by the lake was an old Unitron refractor in excellent condition with this system of tracking.

Late Saturday night, Dick Buchroeder and I found ourselves by the open air chapel where three instruments were set up. One was covered with plastic sheeting against dew and belonged to Cliff Holmes; another was a standard 8-inch Celestron. The third, however, was being operated by its owner and was an equatorial mount upon which three small aperture instruments were attached. The outstanding exhibit was an objective prism over one of the telescopes. We had a splendid view of Vega and the dark lines of hydrogen in its spectrum. By using a cylindrical lens,

A wooden-tubed instrument by Dave Pitou of Sacramento. It contains a 12½" f/5 in a Honduran mahogany tube with a 5" refractor finding scope and a 6" Maksutov guide scope. Primary reworked by Cave, Maksutov by Sky Research, the finder a $20 lens bought at a former Riverside meeting. He made everything but optics on the entire unit.





Award winner Dave Wiley of Santa Monica who was obviously the laziest observer present! His open tube 90mm RFT refractor has a 20" f/5.6 war surplus aerial lens with a Plossl eyepiece. The teak frame tripod pulls down to any viewing position — if one is still awake!

the spectrum was spread out to give a fine set of colors and lines. I had left my camera and tape recorder at the barracks and when I returned several times during daylight and once at night I never found the owner around it again. (The owner later wrote to TM — the 6½° prism belonged to Steve Edberg, the telescope to Rick Shaffer, Kevin Ritschel, and Mark Coco.)

Another fine instrument, a Wright Telescope, was shown to me in the dark by its maker. It had an oblate primary; the corrector at the focus and a diagonal mirror sent the light to the side of the tube for observing or photography. He had a Nagler 9mm ocular on it, and the image of Saturn the same at the center of the field of view as at the edge.

There was a special solar instrument that gave terrific views of the Sun in Hydrogen light. It showed surface features, edge prominences, and part of the inner corona very well. It had no heater for stabilization and the young amateur who brought it said it was not necessary in this new design as the filter was tuneable over 2 angstroms. It was designed by some Lockheed scientists and engineers and built by him, but it would be necessary to get permission from the engineers before details of the construction can be released.

The two-hour swap meet was the most active of events at the meeting and reminded me of bargin day at the local supermarket. It is truly amazing how much material (and money) change hands in so short a time.

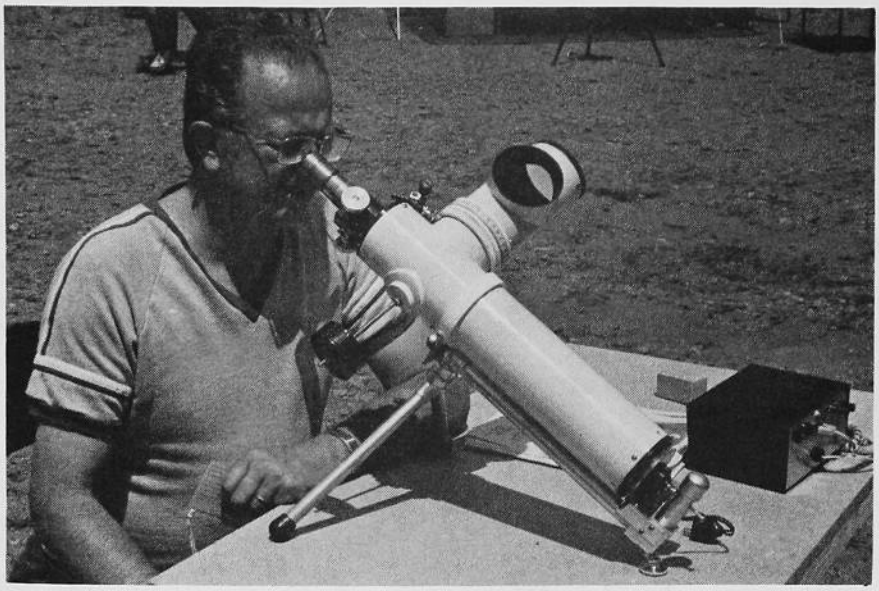
It appears impossible for one person

A tandem instrument of Randall Wilcox of Riverside. The main instrument is a 10" f/7 Newtonian, while the smaller one on the end of the declination shaft is a 6" f/4 Newtonian which is convertible to an f/16 Cassegrainian. The 10" has Coulter optics, but Wilcox personally ground the 6". The mount is homemade — cut out and welded — the drive an 8" Byers. The declination tangent arm is homemade. Used for astrophotography and, when they're around, for photographing comets.

to do an adequate job of covering Riverside. Between examining the instruments and attending paper sessions, you always feel you're missing something. It was necessary to skip most of the papers Saturday morning and early afternoon. However, much outside activity ceased at 4:40 and the lecture hall was full to overflowing when John Dobson presented his paper, "Dobson on Dobsonians." John's work in developing the mounting that bears his name and his present purpose in popularizing astronomy and viewing made fascinating listening. Amateur astronomy owes much to this man.

As this year's recipient of the Clifford W. Holmes award would not be present on Sunday evening, the presentation was made Saturday evening. And who was it? John Dobson of the Sidewalk Astronomers of San Francisco received his plaque and $100 from Richard Poremba and Astronomy for America amid resounding applause from the audience.

Door prizes at 7:15 that evening drew a large crowd that again overflowed the meeting hall. Everyone attending was given a ticket and you had to be present to win. The highlight of the event were the two final prizes: the first an 8-inch Meade Schmidt-Cassegrain and an



Edward H. Pasko of Santa Maria, Calif., demonstrates his table-top fixed-eyepiece telescope of 3" aperture. The extension tube has a flat mirror which rotates about the axis passing down the supporting tube for declination location. The light from this flat strikes a second flat which directs the light down the tube to the 3" mirror through the polar bearing, whence it goes up the polar axis tube, through a hole in the second flat and (finally) to the eyepiece. One can sit and look into a fixed eyepiece position and by positioning the two mirrors, see any part of the sky from pole to horizon. This is a reflecting version of Loewy's Equatorial Coude built in France in 1883 with a lens element in front of the first mirror! In this mirror version, the hole in the one flat acts as a "hole" and causes a diffraction effect similar to a secondary mirror in the light path.

8-inch Celestron Schmidt-Cassegrain.

The invited speaker, Walter Scott Houston, then spoke with his usual blend of wit and humor. Scotty held the audience enthralled.

At 9 p.m., a number left to see if the Pallas/1 Vulpeculae occultation might be visible (it wasn't — we were too far north) and for the others, a movie had been scheduled. However, the program was changed and I was privileged to present "Bob Cox's Time Machine" in which, with about 200 slides, I took the audience back to 1937 to meet the giants of telescope making — Porter, Ingalls, Everest, Paul, Mackintosh — and instruments and people I have met, and meetings attended, with instruments from way back then right up to the present — some 48 years.

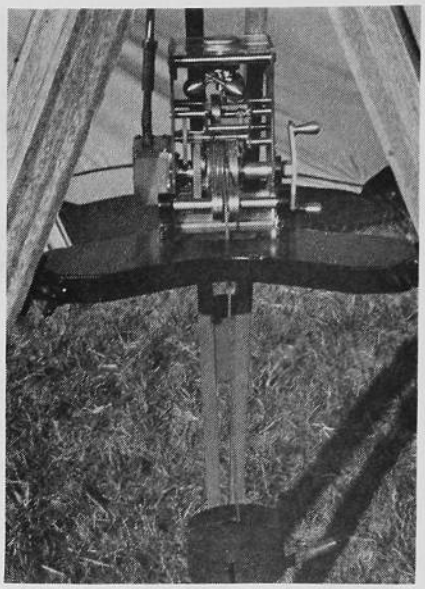
Sunday activities started early: breakfast at 7:45 and at 8:45 various scheduled seminars on optics, astrophotography, and telescope mountings, continuing until lunch time. I participated in the optics and a lively discussion ensued with Dick Buchroeder and Scotty covering a variety of topics. Many questions arose from comments and pictures shown in the "Time Machine" talk, in particular about the use of steel washers in rough-grinding large optics. Using preformed tools of glass or metal to the desired radius, steel washers were cemented to them with hard pitch and the steel surface so formed was used to shape the main optics. As the washers wore out, they were replaced until the curve was reached — at which time they were removed and the preformed tool now used to fine-grind and finish the mirror.

A discussion on mounting large thin mirrors also arose and it was pointed out that no two pieces of glass, especially when thin, will act the same. It seems to be necessary, sometimes, to change a final cell configuration in an instrument that has previously worked if you install a similar, but different, piece of glass.

The optics session went until 10:30 and then another session began on the subject, "Computerization for Amateur Telescopes." This quickly became advanced: along with many others who are just getting into computers, I found it too advanced to be applicable. I left to find some of the people who had asked if I could help them on an optical problem.

After lunch I tried to locate persons who were not at their telescopes before so I could obtain information on their equipment, usually without success, and so did not return to the lodge and papers until Don Davis spoke on his astronomical art endeavors, where he showed slides of excellent and scientifically accurate renderings of astronomical and space subjects.

Award recipient Roger Sanders described how he applied modern techniques to mountings using aircraft type structures, a method useful to large apertures.



A falling weight clock drive that was on a commercial Unitron telescope in one of the observing fields. It was the only one of its kind at the meeting, but I never saw anyone around to give any information on it.

Clyde Tichenor's paper "Kitt Peak Style Observatories" described simple design approaches using as much as possible the principle of straight lines. He has made two units for institutions, but his plans are available to the amateur and are not restricted.

A ceramic mirror made by Patric Canan of Corvallis, Oregon. Canan's 9.5" f/3.8 Newtonian was the smallest and most portable Dobsonian at the meetings.

The award-winning 12½" instrument of Reinhart K. Buchner of Westminster. He has a commercial optical system, but made a fine mount with a built-in West electronic drive. The fork is also commercial; the telescope was built for photometry.

Richard Buchroeder's paper, "The Problem with Eyepieces," described the development of eyepieces from the simplest to the most complex computer-designed types with 14 special illustrations showing optical elements, spot diagrams, aberrations. The design of eyepieces is a special field and important to all observers. The presentation should have proven informative to all present.

All optics are made to tolerances and as a result, the focal lengths of oculars are seldom exactly as indicated. I had the opportunity to present a paper, "Measuring Eyepiece Focal Length and Instrument Power," describing how the amateur could make a lens of known focal length from two separate lenses and then use this and a reticle to develop an eyepiece measuring device. It was an exercise in basic optics which I hope will encourage amateurs to make experiments and learn more about the equipment they work with.

After supper it was awards time again with everyone receiving a ticket for door prizes. First, recognition of excellence in the equipment displayed on the telescope field was made by the awards committee, then the door prizes — again many excellent items were given away, but the last three were block-busters. First there was a Celestron C90 Maksutov, followed by the Criterion 4000 Schmidt-Cassegrainian and finally a 10-inch Compact Odyssey!

Before the regular awards, Cliff

John Dobson demonstrating his solar telescope mounted on the design that bears his name. John was the 1983 recipient of the Clifford W. Holmes award for his contributions to the art of telescope making.

Holmes announced that Rick Shaffer had a special award to make. Rick explained that at a former meeting, Ed Byers attended in a ruffled shirt and formal attire — having been at a wedding and not having had a chance to change. He was now instituting this new award: The 1983 Edward R. Byers Non-Memorial for Over-Dressing at the RTMC for which the recipient would receive an official Whammo Frisbee model FB3. To my horror, I then heard him announce the winner: Bob Cox. Because of equipment, I almost always have a jacket on and it was convenient to carry my tape recorder in a side pocket. However, as I received my Frisbee, Rick leaned over and revealed his real purpose. "Bob," he said, "twitch them!" I had no recourse but to do as he asked.

Sunday-night skies were breathtaking before the Moon rose, but the seeing was still poor. Objects other than deep-sky subjects looked pretty bad, and a strong gusty wind did not help at all.

In retrospect, the 1983 Riverside was not as large a meeting as some past ones, and the Full Moon discouraged deep-sky viewing. Of course, some of the people missing had gone (or were saving every cent to go) to the June 11th eclipse. But those of us who did attend had a wonderful time — and no matter what the conditions, Riverside is an experience rewarding in all aspects of technical and personal achievement.

— Robert E. Cox

An "Unconventional" Equatorial Mounting

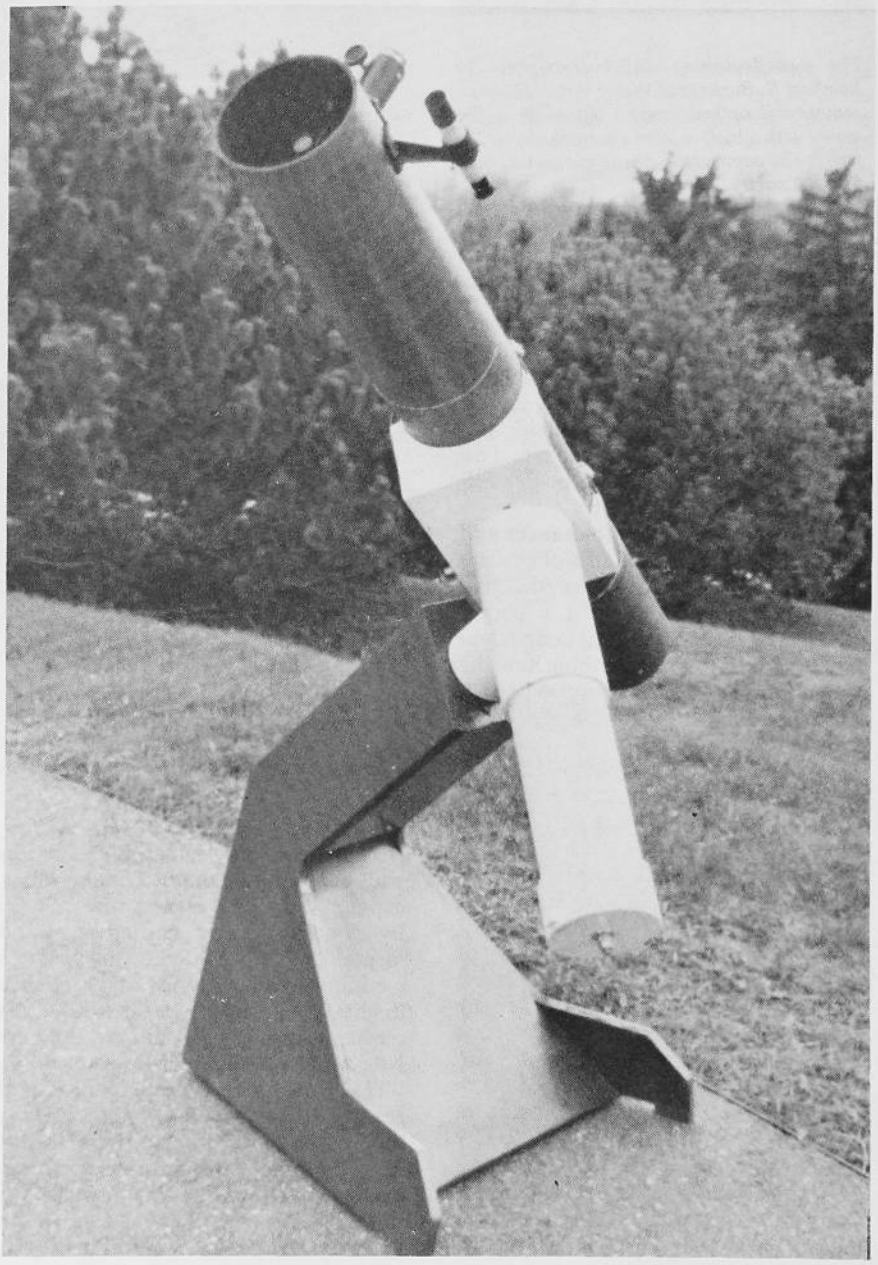
Jack and I have never really liked Dobsonian telescopes. These stout scopes on their alti-azimuth mounts never seem like "real" astronomical telescopes to us — but Dobsonians embody some extremely desirable traits: stability, portability, smooth anti-backlash bearings, and low material costs. If those assets of the Dobsonian could be blended with those of the equatorial, the resulting marriage would be a winner. So it was we set forth to design our "unconventional" mount!

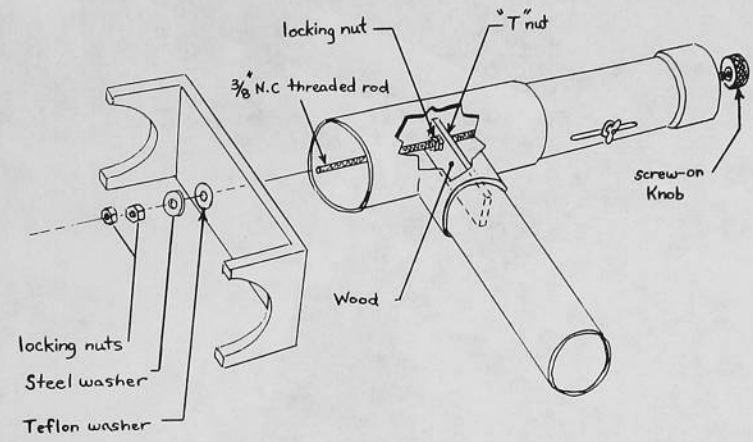
The key to the remarkable performance of Dobsonians lies in the choice of building materials used and how they are assembled. A plastic bearing design is the only way we knew we could achieve a higher dynamic than static friction (which is how a Dobsonian achieves its smooth buttery feel). Rigid PVC, teflon, and plywood were to be the building blocks of our design.

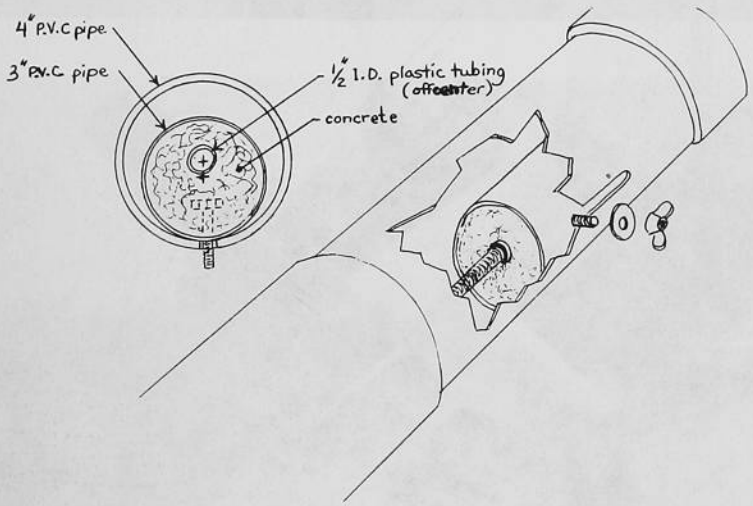
We started small at first, building a mount for a 4.25" f/10 Newtonian to test the design. This mount proved to be a good test bed and taught us much about the factors that affect the performance of our design. The first prototype utilized ¾" plywood throughout and had an RA/Dec assembly consisting of schedule 40 pipe and a 4"x 4"x 3" reducing slip tee.

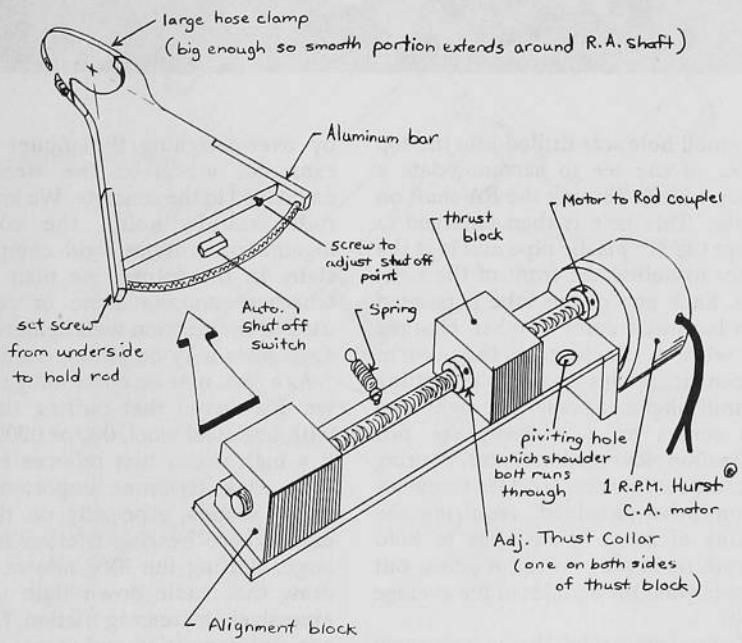
The mounting worked remarkably well. The friction in both axes was very smooth and uniform. The stout design of the ¾" plywood base proved stable as well — even focusing a high power eyepiece was a breeze. Problems with some ovality in the pipe concerned us, though, because we wanted to use a right ascension drive on the mounting. Turning the pipe on a lathe was necessary, but we did it *after* gluing the tee to insure a precise definition of the axis.

In order to gauge the stability of this









mount and those to follow we settled on the following test. A one pound weight is attached to the focuser with string; then while viewing through an eyepiece giving 150 power, we cut the string and timed the dampening of the resulting oscillation. This test is better than tapping the tube because it is less likely to cause secondary mirror vibration. The test favors a short tube telescope due to the shortening of the lever arm; since all our scopes are Newtonians, the test is quite demanding. When this test was performed on our mount, we were quite pleased to find a two-second time for the decay of the oscillations.

Impressed by the performance of the 4.25", we wanted to test it further. We mounted a 6" f/5 tube on the mount. The smooth feel remained, but the vibration test showed that the mount dampened out in just over 3 seconds. It appeared that the heavier counterweights were causing the declination arm to bob. The combined weight of the larger scope and counterweights was also causing the right ascension shaft to deflect some. We corrected this problem by building a stronger RA and Dec assembly with thicker (and more expensive) schedule 80 pipe, shortening the space between the RA bearings, and going to a shorter, stiffer Dec arm. Another neat trick we tried on this mount was incorporating an internal sliding counterweight. A section of smaller diameter plastic pipe filled with concrete can be used on scopes up to 6"; above that size one must use steel as the counterweight material to keep the Dec arm from getting excessively long. These changes improved the dampening time and put us back in the 2-second range.

We felt to really prove the potential of this design, we had to scale it up larger still. The largest telescope I own is a 10" f/5.6, so it was the logical choice for the experiment. In order to isolate vibration to the RA/Dec assembly, we constructed the base from one-inch plywood with a design that gives quite direct load paths. The joints were dadoed and rabbeted where appropriate for maximum strength. This base, unlike that of the first mount, separates into two pieces for portability.

The RA/Dec assembly consists of 4" sch. 80 and 6" sch. 40 pipe joined to a 6"x 4" reducing slip tee. This combination gives a 4.5" o.d. RA shaft and a 7" o.d. Dec thrust surface. These specifications, though impressive sounding, gave less than impressive results. When tested, vibrations dampened with slow oscillations in over 4 seconds. This, though better than many mounts, was about twice what we were hoping for. The problem results

from the fact that simply scaling up works only over a limited range. We had exceeded that range — and the forty pound weight of the tube was the culprit.

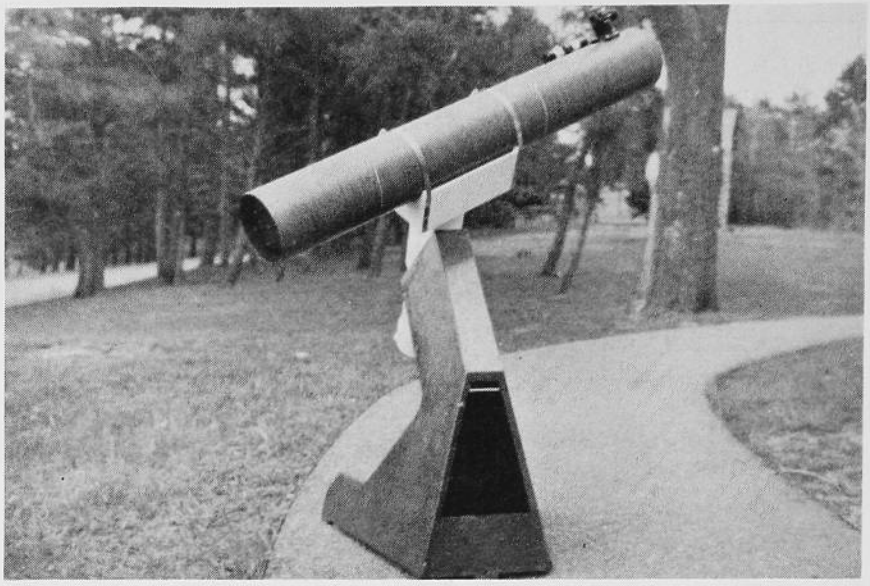
We needed to make the plastic stiffer. To do this we experimented with filling the interior of the pipe and tee with pre-stressed reinforced concrete. This was done in two pours. The first pour was to bond one end of the rods in place, followed by the second around the torqued rods. The concrete should ideally be poured and cured at a slightly elevated temperature (in your house) to assure an interference fit at normal viewing temperatures. The concrete was mixed with minimal water for maximum strength and when poured, the plastic was tapped with a plastic mallet to guarantee complete filling.

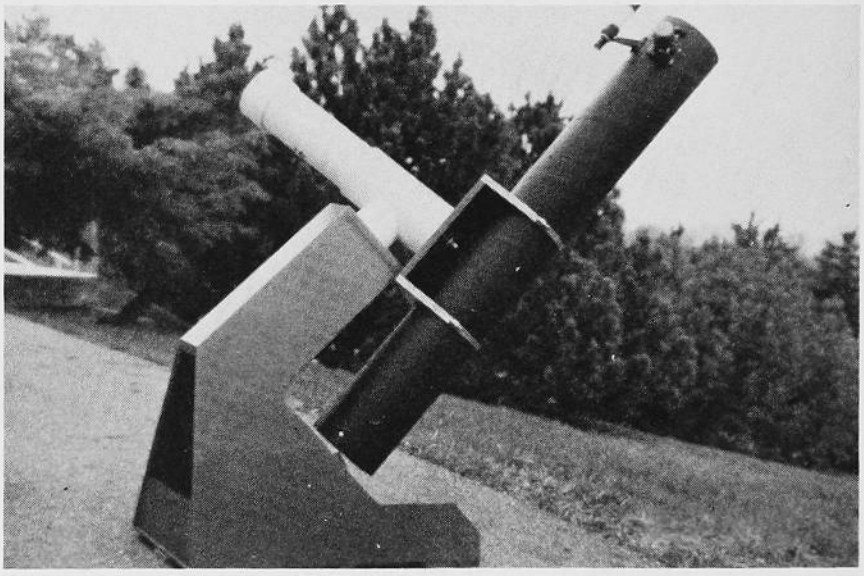
When the poured assembly cured fully, after about a month, it was put in the mount and tested. Vibration times were in the 2 second range.

The cost of this improvement was weight, some 65 pounds of concrete and steel. This caused some problems. Initially we had hesitated to use thin strips of Teflon for the RA thrust surface because of its low compressive strength. Instead we had dadoed in ½" x ⅝" bars of Moly-Disulfide-filled nylon which is harder and lower in friction than plain nylon. This combination had worked well before the concrete was added, but with the concrete, friction was excessive.

As a last resort, we added 1/16" thick teflon strips to the frictional areas. The improvement was dramatic. The friction was now *less* than before the concrete was added. Friction was once again low enough that a RA drive with a slip clutch could be used. The mount now exhibits all the smoothness and stability of a well-made Dobsonian with the big advantage of equatorial tracking! This mount won Second Place for Mechanical Design at Stellafane 1982, and appears on the cover of TM #17.

We then constructed a second RA/Dec assembly of lighter weight. This was accomplished by inserting a length of 3" thin-wall PVC pipe to displace concrete in the counterweight arm and by using a greater number of thinner rods (eight ⅜" N.C. rods in the RA shaft instead of four ⅝" N.C. rods). We also experimented with spring counter-weighting to reduce weight. These steps resulted in a weight savings of almost 25 pounds. We also decided to cast-in an offset Polaris-finder tube. We used the Dec arm as a directional locator of the pointer stars of Ursa Major. Once this alignment is made, the offset tube is then properly oriented for Polaris sighting.



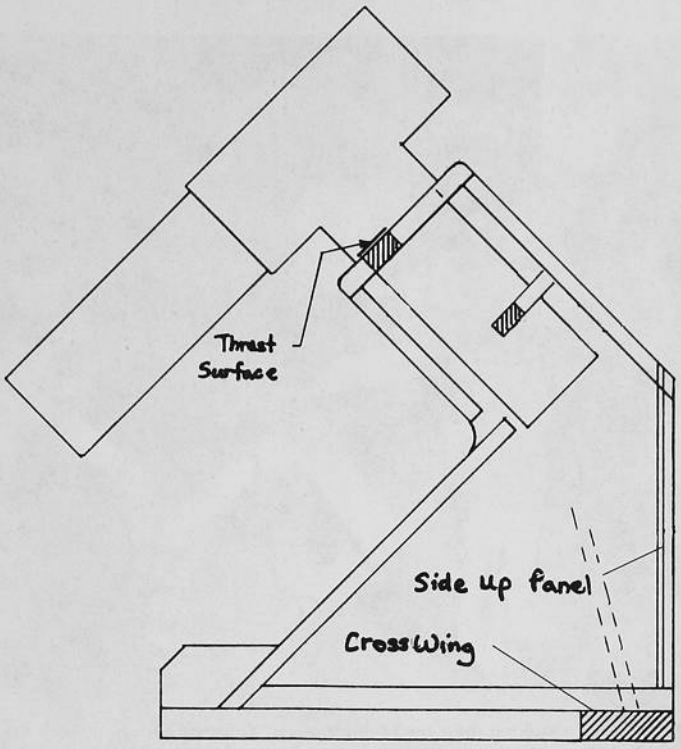


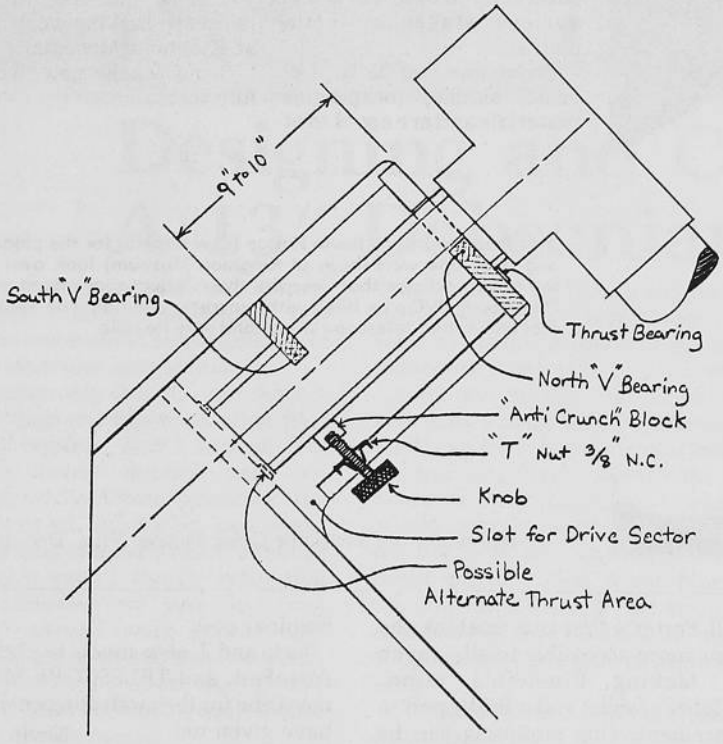
A small hole was drilled into the top center of the tee to accommodate a steady rest for turning the RA shaft on a lathe. This hole is then enlarged to accept the ¾" plastic pipe and is at the center to define the front of the sight tube. Each end of the tube is painted with luminous paint — when charged up with a flashlight, they form concentric circles that make getting accurate alignment easy. The sight tube also serves as a wireway for our declination slow motion motor. Pouring concrete for this new RA/Dec assembly is somewhat involved, requiring the making of some special jigs to hold everything in place while it cures, but is not beyond the abilities of the average ATM.

We have always felt that many people try to attach too large a telescope to a given mounting. We have compensated by over-designing the mount — for example, we used the steel rods embedded in the concrete. We knew the rods would "hold" the concrete together in a more rigid compressed state. In the future, we plan to test whether concrete alone or concrete used in conjunction with lighter weight aggregates may be strong enough.

As a final note on controlling friction, we discovered that buffing the PVC with fine steel wool, 000 or 0000, gives it a high sheen that reduces friction. This trick becomes important with heavy scopes, especially on the Dec axis, where bearing friction is fairly large. Buffing the PVC allows you to draw the cradle down tight without excessively increasing friction. Car wax has also been tried and seems to help.

The right ascension drives used on our mounts have evolved greatly and





are quite a story in themselves.

The accuracy and precision of any clock drive depends on the following factors. First is the effective radius of the worm gear sector. With all else being equal, the larger the radius and the smaller the periodic error, the easier it is to achieve the exact radius needed for long-term drive rate accuracy. A large radius also reduces backlash and tooth loading. Another important area is the precision of the tooth spacing. This is the area where most periodic error is introduced. Other areas affecting performance are the accuracy and precision of the motor, stability of local A.C. current or the drive corrector, if one is used. A final gremlin that is often overlooked in drives concerns the runout between the captured worm and its housing. (This is not to be confused with worm-to-housing backlash.)

Our drive utilizes a curved piece of 3/8'' rolled thread rod driven by a straight piece of the same rod. This straight rod is driven directly by a 1 RPM CA-series Hurst synchronous motor. The curved section has a radius of 14.47 inches as measured to the outer edge of the curved rod. We formed it by bending a rod around a carefully cut section of plywood of approximately 9'' to 10'' in radius (the exact radius of this forming board will fluctuate depending on the hardness of the rods you use). This configuration is commonly referred to as a ''curved bolt'' drive. Our drive is a heavily modified version of the original design pioneered by Ed Jones of Dayton, Ohio. (Thanks Ed!)

We originally had calculated the radius from a formula given by Mr. Jones to be 14.29 inches. The formula is:

$$R = 1436.5 \times N/2 \times \pi \times T$$

where R = radius, N = motor speed in RPM, and T = number of threads per inch. When first tested, our drive was slightly fast because this formula does not take into account the widening of the teeth in the forming process on the outer edge of the sector rod. To compensate for this effect, the radius must be increased by half the rod diameter (3/16'' in our case) to achieve the correct drive rate. As of the time of writing this article, the drive has a periodic error of only 15 arc-sec per turn of the worm. We expect the periodic error to fall below 10 arc when we refine the turning rod's thrust block squareness. In the future we plan to experiment with precision ground threaded rod as well as our own lapped rods. The layout of the drive is best conveyed in picture form.

Incidentally, pay fairly close attention to the details in the drawings. Little

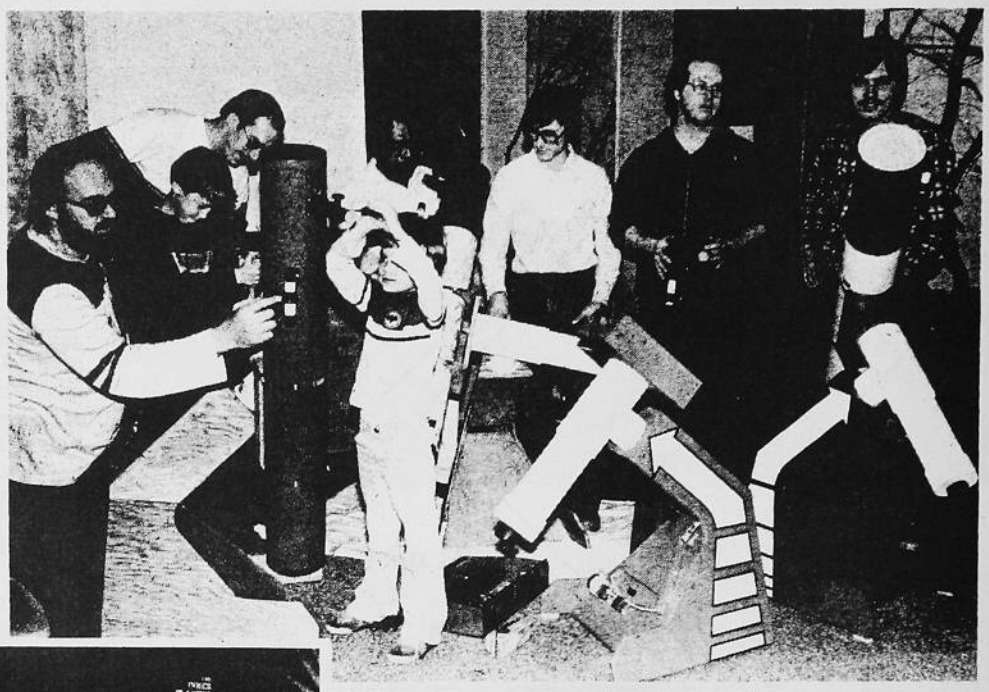
Kevin Hotton and Jack Roach bring new worlds into focus

Kevin Hotton and Jack Roach have made the cover of "Telescope Making", a magazine published quarterly "for, by and about telescope makers."

Their new technique for making "an equatorial mounting built from heavy PUC pipe filled with concrete and riding on Teflon pads' was also described in the December '82 edition of "Astronomy" magazine and in the November '82 edition of "Sky and Telescope" magazine.

With only one machined part, their telescope can be made quite inexpensively and function accurately and efficiently.

To the the layman, making a telescope sounds very technical and mysterious.



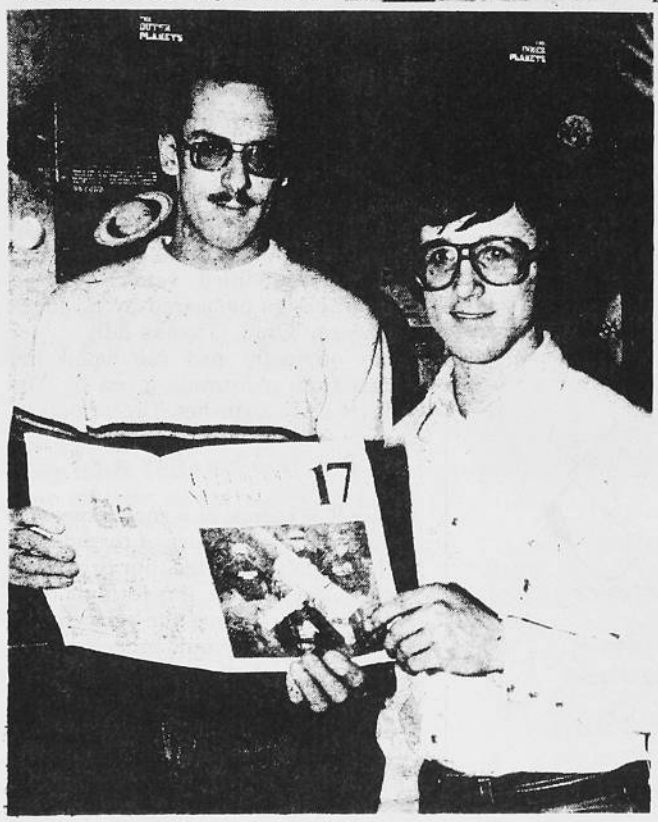
Making their own telescopes at Kingman Museum, with the help of Jack Roach (back, left) and Kevin Hotton (center) are Al DiGennaro and his sons, Brian and Greg, Bill Washington, Doug Lindsey, and Patrick Cieslak.

But all one needs to do is stop by their area at Kingman Museum and take a look at several telescopes that are in various stages of completion.

Telescopes can be built of basic, simple, inexpensive materials and are equal to or even better than commercially built ones.

Kevin and Jack can show you how in one of the telescope-making workshops at Kingman Museum.

Bring whole new worlds into focus.



Jack Roach (left) and Kevin Hotton (new director for the planetarium and telescope workshops at Kingman Museum) look over one of the recent articles that describe their "equatorial mounting" built from heavy PVC pipe filled with concrete, and riding on Teflon pads that make their telescope sturdy and very flexible.

— reprinted from *The Battle Creek Shopper News*, Dec. 16, 1982

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things count. For example, the "anti-crunch" block should be just beyond the south V bearing. When you slide the polar axis in, it's tipped high so that it first contacts the anti-crunch block — then you decrease the tip until the bearing rests against the south V block.

The reason we designed this mounting in the first place was to follow Russell Porter's theme of making the heavens more accessible to all — even those lacking Einstein's mind, Rockefeller's wallet and a Bridgeport in the basement. Our mounting can be easily constructed by anyone. For those wanting more information, please feel free to contact us. We can supply glued and lathe-turned tee assemblies at a nominal cost.

Jack and I owe much to Stellafane, AstroFest, and TELESCOPE MAKING magazine for the motivating energy they have given us!

Kevin Hotton
Jack Roach
544 Orleans
Battle Creek, MI 49015

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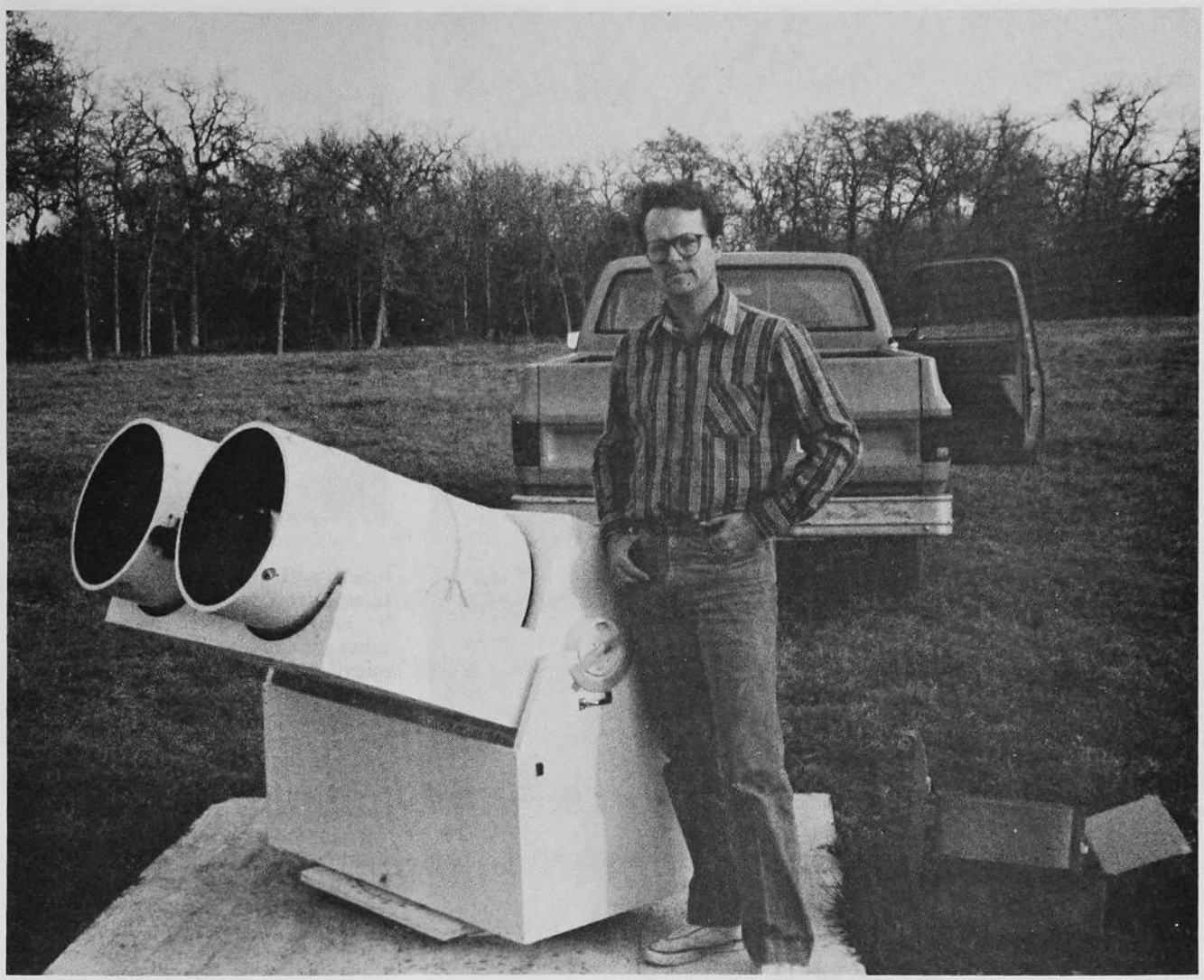


Designing and Constructing A 13″ Dobsonian Binocular

While using a friend's 80mm binocular, I noticed something that made me reconsider the possibilities of a large binocular instrument.

It is commonly thought that there is no advantage to a binocular other than viewing comfort. But I noticed that when I viewed through only one eyepiece of the 80mm binocular, the image seemed inferior in two ways. First, the field seemed smaller, although of course it wasn't. But the effect that really interested me was that faint extended objects were *much* more difficult to see with one than with two. While the first effect was purely illusory, I think the second was a matter of really seeing more.

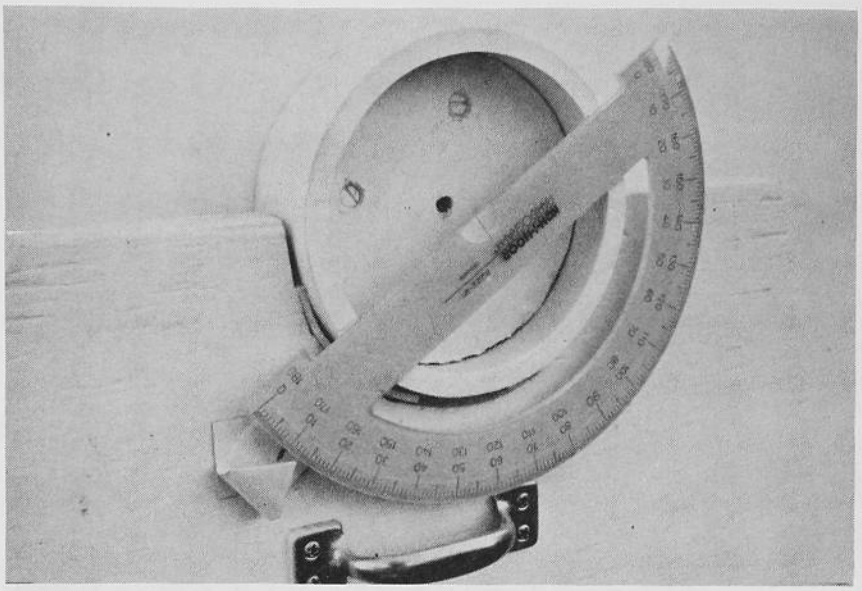
The basis of my project is that when both eyes work together on an image that is at the threshold of visibility, the brain can work with the images synergistically to form a brighter and higher resolution "brain image" than with the same amount of glass in a monocular telescope.

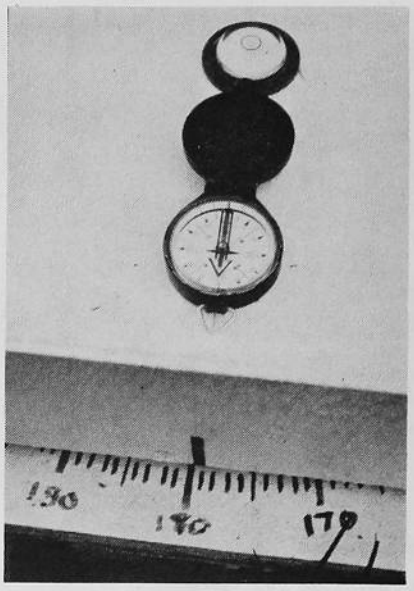
Why not simply put a binocular viewer on a larger monocular telescope? First, two mirrors usually cost less than a single larger mirror with the same total area. For example, two Coulter 13" optical sets cost less than a single 17.5" set, but have 12% more area than the larger mirror. Also, most binocular viewers cannot handle the steep light cone of a fast focal ratio and the number of optical surfaces tend to degrade the image.

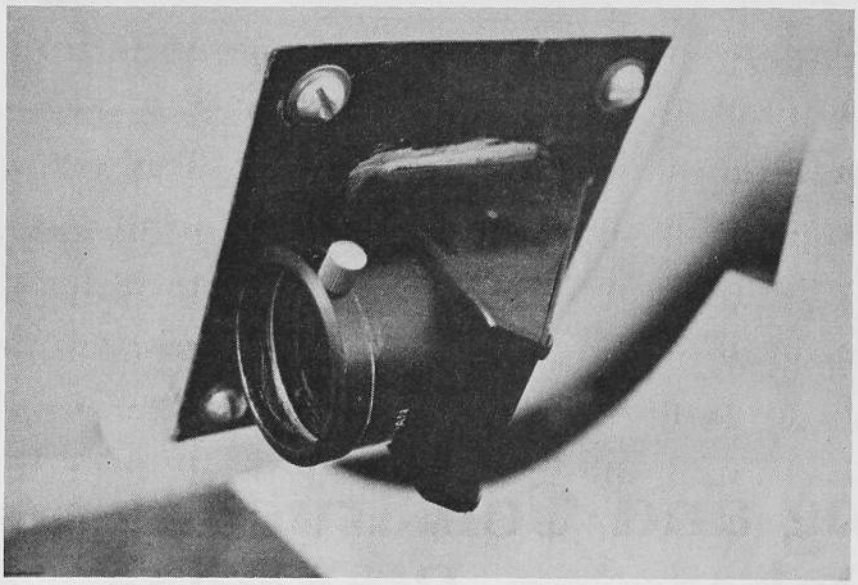
I decided to build what is essentially a fast, wide field, double Newtonian based on the 13" mirror sets available from Coulter. This gives 254 sq. in. of useable objective area, or 16 times as much collecting area as an 80mm binocular and 5.4 times that of a C-8. In terms of total light, it's comparable to using a binocular viewer on a 19" Newtonian telescope.

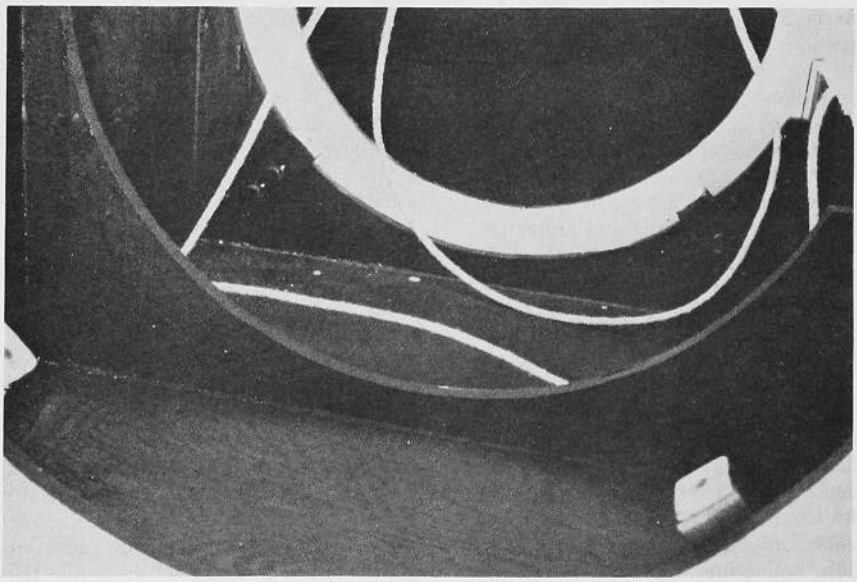
Mechanically, the telescope is simply a side-by-side double Dobsonian. Construction is of plywood. Altitude/azimuth bearings are the typical Teflon/Formica type. Though a homemade wooden instrument can only be relatively crude and a binocular must be very precisely aligned, designing in enough adjustment for every component can provide for final alignment.

To bring the two images to parallel eyepieces, I chose to bring the images out the sides of the tubes, Newtonian fashion, and through diagonals to eyepieces placed between, and below, the centers of the tubes. The observer stands between and slightly below the







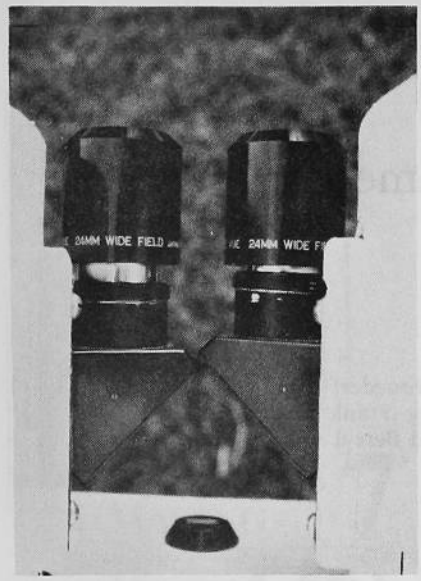


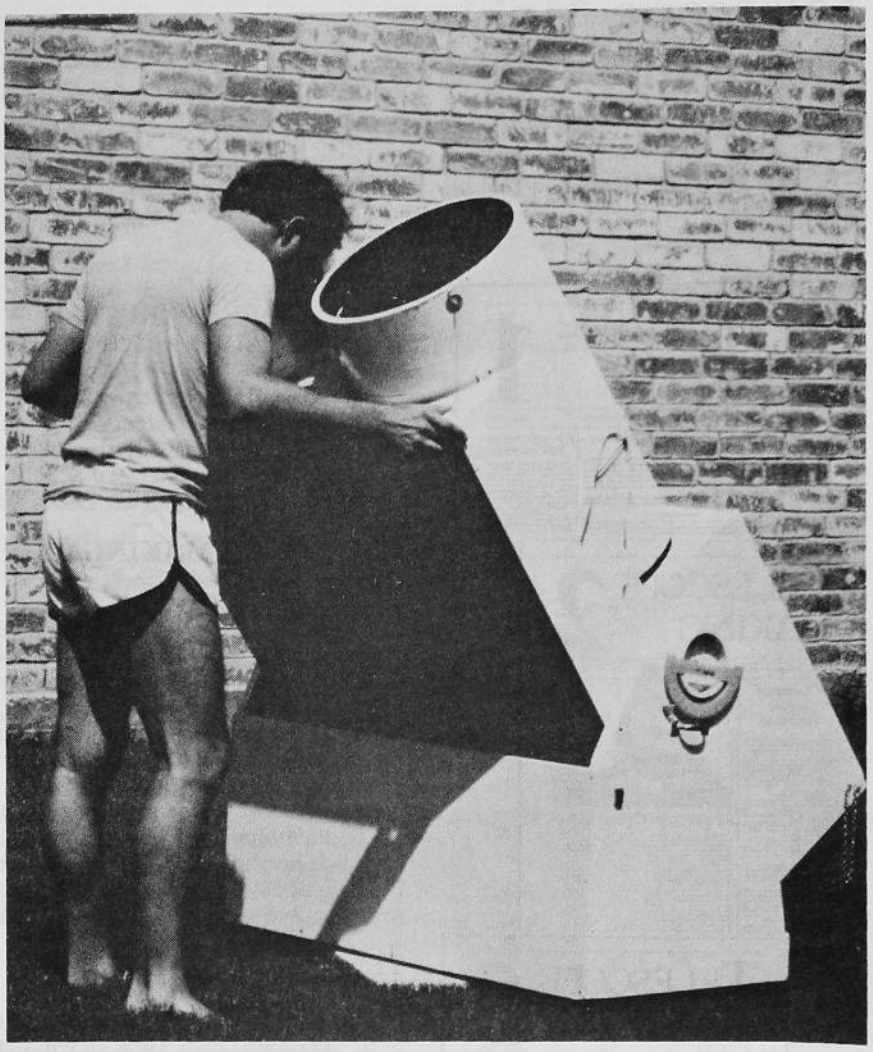
tubes with his back to the sky. Interocular distance adjustment is made by rotating the front section of the tubes, which moves the secondary mirror and diagonal and the eyepiece as a unit. Since the secondary mirror and diagonal stay in opposition to one another, the images remain oriented properly. The primary mirror is not rotated so it can be mounted in a Dobsonian sling rather than a full cell.

No refocusing is necessary after making an interocular adjustment as it would be if the adjustment were made by racking the diagonals in and out of the tubes. This system has the added advantage of allowing rotation of the eyepieces to opposite sides of the instrument so two observers can view the same object at the same time. The tubes rotate on Formica tracks wrapped around them and resting on adjustable Teflon support pads in the main box. This system requires that the tubes be truly round, so I made each tube double wall thickness by slitting one tube and gluing it inside another with braces of proper diameter placed inside while the glue dried. They are made to counterrotate equal amounts by a dacron cord wrapped around them and interconnected by pulleys in the box below. The pulleys are mounted on elastic cords which provide tension that holds the tubes firmly against their supports to maintain alignment.

I chose the new 24mm TeleVue wide-field eyepiece. The 5.5mm exit pupil makes interocular adjustment less critical and slight vertical misalignment if the two images can be unconsciously corrected by the observer slightly tilting his view through the eyepieces. The magnification is 61x with about a 1° field and an apparent field of 65°.

Such eyepieces see a large image at





the focal plane, and full-field illumination becomes a challenge especially with a fast focal ratio. I "opened up" 1¼" Meade star diagonals by removing the objective barrels and shortening the subjective barrels to the minimum that would allow enough focus for different observers. Finally, the diagonals were mounted as close to the tube as possible. I believe I now have better full-field brightness than most fast Newtonians with the ordinary tall focusers.

Mechanical alignment was done during construction and should be permanent. It was done by viewing, with no mirrors, through a hole in the tailgate at each optical axis, past a temporary crosswire in the rear of each tube, through a hole in the center of the spider and to spots on a sighting board placed a few feet in front of the tubes and level with the tailgate. I made adjustments to the pads supporting the tubes to make them parallel and in line with the centers of the primary mirror cells.

The mirrors are installed with each use so field alignment is required. Viewing through each diagonal, without eyepieces, each secondary is adjusted in rotation, then each spider is adjusted to center the image of the primary mirror. Then each primary mirror is adjusted to center the image of the secondary mirror. Finally, viewing through both diagonals at the same time, the secondaries are adjusted to merge the images of the primary mirrors and then the primaries are adjusted to merge the images of the secondaries, so it appears you are looking into the focuser of a monocular Newtonian telescope. The eyepieces are then added and star images are merged by adjusting the primary mirrors. The vertical adjustment is the most critical — horizontal less so. The eyes are parallaxed to a focus a little short of infinity, and they can compensate for slight variations horizontally.

At the first test, I was very pleased with the results. First of all, the images from the two optical trains were of the same magnification and oriented the same, thus easily merged. The image was very bright and clear. Indeed, when I viewed through only one of the eyepieces, then through both, the "brain image" effect was even more pronounced than it had been with the 80mm binocular. The 65° apparent field seems even wider using both eyes. An effect I hadn't expected was the variety of color among the stars. I enjoyed just scanning the sky which is something I rarely did with my C-8. There is no actual 3-D effect but there is an illusion of greater "image reality" when the brain gets information from two sources.

The mount is very smooth and stable. The instrument is modular and comes apart quickly, and I discovered I can move it and set it up alone — but just barely. The size and viewing angle, except at the zenith, make observing very comfortable. Every couple of hours, though, a small adjustment must be made to the primary mirrors to remerge the images.

I use Lumicon Deep Sky filters for backyard observing and for viewing emission nebulae even from fairly dark skies. They're mounted in brackets in front of the diagonals to avoid any vignetting. I use setting circles and a Radio Shack pocket computer to find objects. It is programmed with latitude, longitude and time zone for my club's observing site. For each observing session, I enter the month and day. For each object, I enter the right ascension, declination and local time. The computer can also do the conversion in reverse to yield the right ascension/declination from altitude/azimuth.

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Telescope Making Cumulative Contents and Guide to Back Issues

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An Inexpensive 4" f/10 Reflector (Richard Berry)
Making Pitch Laps (Sherman Schultz, Jr.) *
Making a 3" Schiefspiegler (Oscar Knab)

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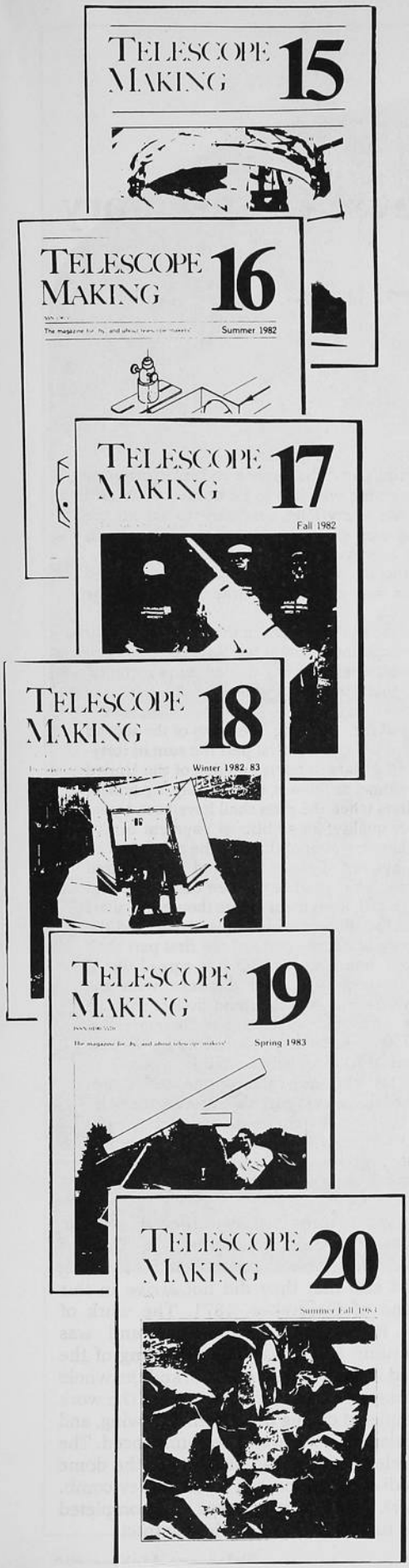
letter code key:

D — Reprinted in "How to Build a Dobsonian Telescope, 2nd Edition"
O — Reprinted in "How to Build Your Own Observatory"



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V — Venrooij and Rutten Optical Raytracing Series
H — Article of Historic Interest
* — Especially Useful Information

The XXVI-Inch Equatorial of the Naval Observatory

Prepared by Professor Edward S. Holden, U.S.N.

Section 18 of the "Naval Appropriation Bill," approved July 15, 1870, contained the following provision:

"That the Superintendent of the Naval Observatory be, and he is hereby, authorized to contract for the construction of a refracting telescope of the largest size, of American manufacture, at a cost not exceeding fifty thousand dollars."

Immediately upon the passage of this bill negotiations were entered into with the firm of Alvan Clark & Sons, of Cambridge, Massachusetts, resulting in the conclusion of a contract for the construction of the instrument, in the following terms:

"This indenture, made and concluded upon this thirteenth day of August, in the year one thousand eight hundred and seventy, between Alvan Clark, George B. Clark, and Alvan G. Clark, all of Cambridge, Massachusetts, and doing business under the name and firm of Alvan Clark & Sons, as the party of the first part, and the United States of America, represented by Commodore B.F. Sands, U.S.N., Superintendent of the Naval Observatory, by authority of the eighteenth section of the act making appropriations for the naval service for the year ending June 30, 1871, approved July 15, 1870, as the party of the second part, witnesseth:

"That, for the considerations hereinafter mentioned, the said party of the first part agrees to construct, finish, and mount in the United States Naval Observatory, Washington, free of all expense to the party of the second part, a refracting telescope of good definition, and of twenty-six inches clear aperture, mounted equatorially on the German plan, with all the usual and necessary counterpoises and other devices to secure its easy motion, its proper balance in all positions, and the safety of its object-glass; with divided circles, to be each read by two microscopes; the R.A. circle to seconds of time, and the Declination circle to tenths of a minute of arc; with a driving-clock sufficiently regular and powerful to secure an equable and steady motion in right ascension, for a period of at least three hours without stopping; with the usual number and description of eye-pieces and ring-micrometers; with a filar micrometer for measuring distance and angle of position; an Airy's double-image micrometer, and a divided glass or mica-scale micrometer. The said telescope shall also be furnished with such spectroscope, such devices to secure successful and easy manipulation, and such apparatus for illuminating the wires, the field, and the circle-divisions, as the party of the second part may prescribe, it being agreed, however, that no spectroscope shall be required by him of which the total necessary expense of construction shall exceed one thousand dollars, and that no new devices or apparatus thus prescribed shall be of an unusually expensive character.

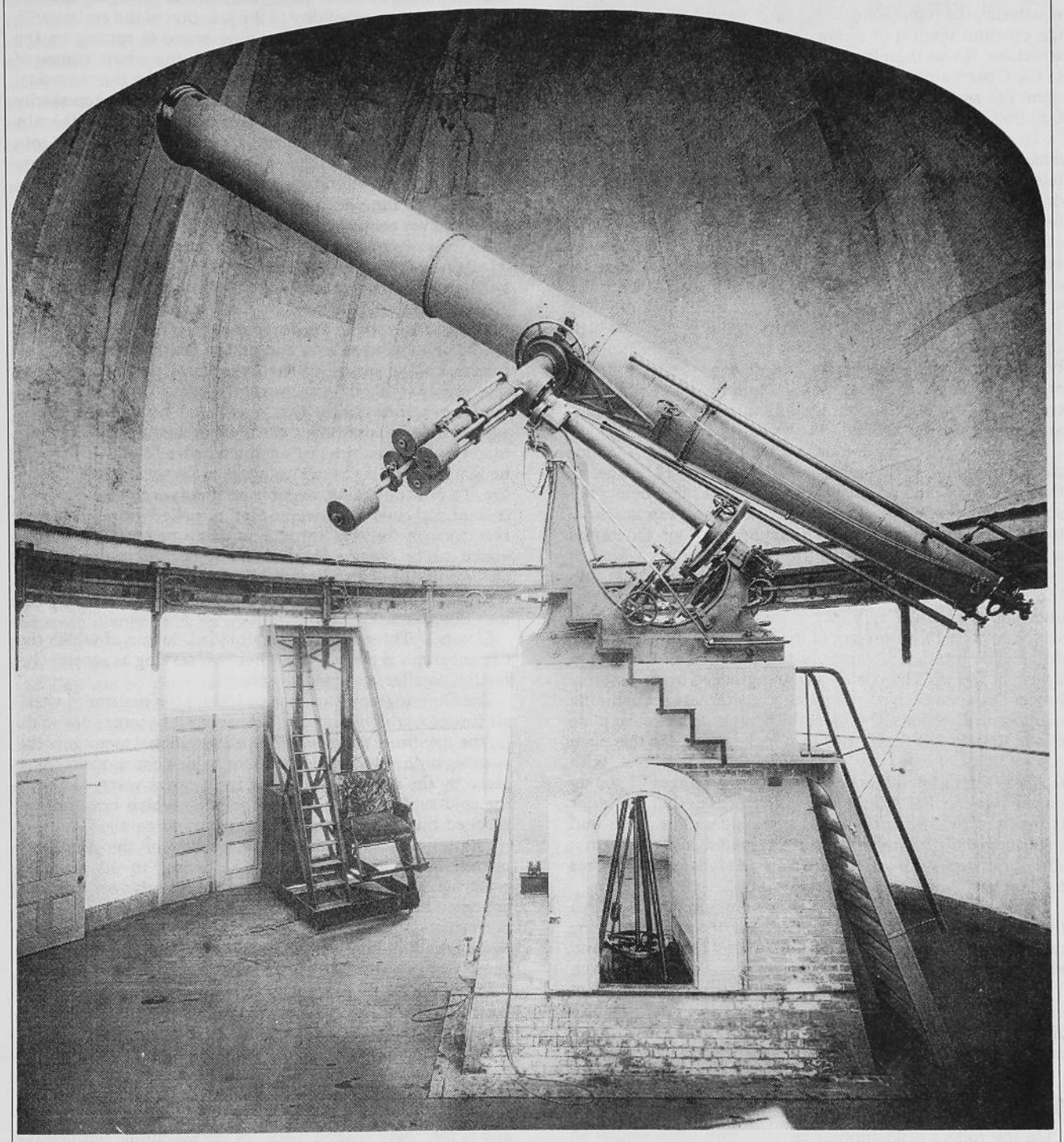
"It is also agreed that the party of the second part shall build at his own expense a proper foundation of the instrument, to include all that part of the support which is commonly built of stone, and to be terminated on top by a horizontal surface, and that the contracting party shall furnish and put in complete working order everything which is to be borne by the said surface, and shall do everything necessary to secure the successful working and performance of the instrument, whether otherwise expressed in the contract or not.

"It is also agreed that the said instrument shall be completed and mounted within four years of the time of receiving the first payment.

"It is also agreed that all the designs of the instrument shall be submitted to the Superintendent of the Naval Observatory and be approved by him before being carried into execution, but such approval shall not be construed to diminish the responsibility of the contractors.

"In consideration of the foregoing, the party of the second part agrees to pay the party of the first part the sum of forty-six thousand (46,000) dollars in lawful money of the United States, in time and manner as follows, that is to say, a payment of ten thousand dollars when the glass shall have been tested and found of proper quality; an additional payment of five thousand dollars when the labor of figuring the glass shall be half performed; a payment of seven thousand five hundred dollars when the said labor shall have been completed and the glass proved in its cell; a payment of five thousand dollars when the instrument shall be ready for mounting; and the remainder of the price when the party of the first part shall have fully completed their contract. But it is agreed that if the party of the second part shall dispense with the spectroscope, a deduction of one thousand dollars shall be made from the above-mentioned price, and, furthermore, that if the United States shall remit the import-duty on the raw material, or any part of it, a deduction shall be made from the price equal to the currency-value of the duties thus remitted. The party of the second part also reserves the right, before making any payment, to require the contracting party to enter into a bond with approved security, conditioned on the faithful performance of the contract, and to insure the work against injury by fire at their own expense."

The glass disks were immediately ordered by the contractors from Messrs. Chance Brothers & Co., of Birmingham, England, but such was the difficulty of casting disks of the required size that they did not arrive in this country until the end of December, 1871. The work of figuring them was immediately commenced and was completed in the autumn following. The mounting of the telescope was finished in the summer of 1873, and the whole was brought to Washington in October of that year. The work of mounting was completed during the month following, and on November 20 regular observations were commenced. The construction of the telescope and the building of the dome was under the immediate direction of Professor Newcomb. It is worthy of remark that the instrument was completed in less than half the time stipulated in the contract.



Heliotype. James R. Osgood & Co., Boston.

THE XXVI-INCH EQUATORIAL

U.S. NAVAL OBSERVATORY, WASHINGTON. MOUNTED 1873.

OBJECT GLASS | Focal Length, 32 ft. 5.8 in.
Clear Aperture, 26 in.

The Dome

The erection of the instrument upon the Observatory building would have required the removal of the old 10-inch equatorial, the remodeling of the interior of the building, and the erection upon it of a dome out of all proportion to the structure. It was therefore decided to extend the south wing of the Observatory, and to place the floor of the great dome upon the same level with the main floor of the rest of the building. The disadvantages of this course were believed to be far more than counterbalanced by its advantages. The only disadvantage to be taken into consideration is, that the telescope cannot sweep the horizon. In the north, the old dome rises to an altitude of about 16°, while in other directions the surrounding trees interfere with the view to an average height of perhaps 10°. This drawback is however entirely unimportant, for the reason that with so large an instrument astronomical observations can never be advantageously made so near the horizon. During the two years' use of the instrument no case has yet arisen in which the view of any object which it was desired to observe has been cut off by these obstructions. The advantages of the arrangement are cheapness and simplicity of construction, convenience of access from the adjoining computing-room, and partial protection from the wind.

The *foundation* of the dome is rubble-stone, 43 feet exterior diameter, and 2 feet thickness of wall. It extends 17 feet below the main floor, and on the average, about 12 feet below the surface of the ground. This stone foundation extends only to the bottom of the joists which support the floor. On it rests a circular sill of oak timber in 8-foot sections, which is fastened down by iron anchors, each extending 3 feet into the stonework. On this sill rest vertical posts of oak timber, alternately 6 inches by 6 inches and 3 inches by 6 inches, which form the frame-work of the cylindrical portion of the dome. The interior diameter of this portion is 41 feet, and its height 14 feet. These joists are strengthened by six diagonal braces between each pair of posts, the alternate set inclining in opposite directions. On top of the posts rests a circular plate of oak timber, 8 inches broad by 4 inches high. On this plate rests a plate of iron, cast in pieces about 6 feet long, with flanges 5 inches wide on the edges, which flanges fit snugly on the two vertical sides of the oak plate, so that the latter is inclosed by iron surfaces on three sides. The inner and outer edges of the iron plates are elevated so as to form a sort of railway, with convex surfaces, the rails being 6 inches to 7 inches apart from centers.

On these rails rest the rollers, sixteen in number, on which the dome turns. These are conical in form, the outer end being enlarged in the proportion of the distance it has to move, and each is supplied with a pair of flanges to prevent end motion. These rollers are connected by a link coupling, like that employed by Mr. Grubb in the dome of the Dublin observatory, which, at the same time, keeps the rollers at the proper distance apart, and maintains their axes in a line passing through the center of the dome. The principal deviation from Mr. Grubb's system is, that his three narrow rollers are combined into a single wide one.

On the rollers rests another circular iron plate similar to the one upon which they rest, except that only the central part, about 3 inches broad, rests on the rollers, and that on the inside a horizontal flange, about 3 inches wide, is cast. Sixteen friction-rollers are supported at various points about the drum of the dome, which consist essentially of horizontal wheels, whose vertical rims are close to the vertical flanges of this circular plate, and which project slightly over its horizontal flange just described. Between the vertical flanges is set the 8-inch by 4-inch wooden sill on which the dome is built.

The dome is of the hemispherical pattern, the lower 3 feet, however, being as usual, cylindrical. The opening is 6.5 feet in width, and extends nearly 6 feet beyond the zenith. The sides are formed by two strong arches, into which all the smaller ribs are nailed. To prevent lateral springing of these arches, and to give solidity to the junction of the arches with the ribs, a 12-inch by 1-inch pine board is sprung on the frame-work under each arch, through the whole course of the latter, its outer edge being flush with the inner vertical surface of the arch. As the surface of this board is necessarily cylindrical, instead of spherical, the under edges of the ribs are notched away sufficiently to allow the board to fit into them, and the board is then nailed to each of them. That there has been no such lateral springing has been shown by careful measures of the width of the slit at various times. These arches have, necessarily, a powerful end thrust, tending to force the lowest circle of the moving portion of the dome into an elliptical form. This has been provided against by shrinking two bands of wrought iron, about 15 feet long, on the outside of the dome, so as to prevent such change of shape.

The frame-work of the dome is covered on the outside by sheets of galvanized iron and on the inside by canvas. The canvas on the inside of the cylindrical portion has been thoroughly soaked with several coats of soluble glass. Experiment has shown that it will not blaze when fire is applied to it, but only slowly smolder in such a way that some time would be required before the wooden frame-work could be ignited even if the canvas were to be accidentally set on fire. To provide against possible accidents of this kind, a hose is kept attached to a water-pipe supplied from the main reservoirs of the city, through which a powerful stream of water can be at once directed to any portion of the interior of the dome or of its adjacent office and bed-room. This hose is kept in working order in one of the closets opening directly into the dome.

Closets — Three closets are provided, in one of which the Chronograph is placed, the other two serving as receptacles for the smaller apparatus, tools, etc.

The Chronograph-closet has within it the register of a hot-air furnace, which is opened whenever it becomes desirable (in the day-time, and not during observations) to prevent the *sweating* of the pier and instrument, which occasionally takes place by the deposition of dew from moist warm air upon the cold surfaces of the telescope, etc., which have not yet reached the temperature of the surrounding air.

The temperatures inside and outside of the dome are usually very nearly the same, owing to its peculiar construction; generally within 5° of Fahrenheit's scale. Ample provision has been made for securing this essential to the good performance of a large telescope, in the two windows and in the two wide doors of the dome, which are usually opened shortly after sunset on clear days.

The dome is lighted by eight gas-burners arranged at nearly equal distances around the drum or cylindric portion, about 6 feet above the floor. There is also a gas-pipe led around the pier, about 2 feet from the floor, in which are six stop-cocks, to which flexible-rubber tubes can be fitted, one on the north and south ends and two on the west and east sides. From this pipe a branch goes up the north end of the pier and of the "harp-shaped piece" of the mounting, terminating in two burners near the north end of the polar axis.

The dome is moved by means of a pinion of cast iron, 10 inches in diameter, which works into a rack, also of iron, cast in sections of about 4 feet in length, screwed firmly to the inner surface of the dome. This pinion is on the same horizontal axle as a cast-iron wheel, 3 feet in diameter, in whose grooved edge an endless manilla rope, 1 inch in diameter, is laid. This simple device has proved satisfactory, after two years' service. A pull of about fifty pounds is sufficient to start the dome to move, and less than this will preserve the motion.

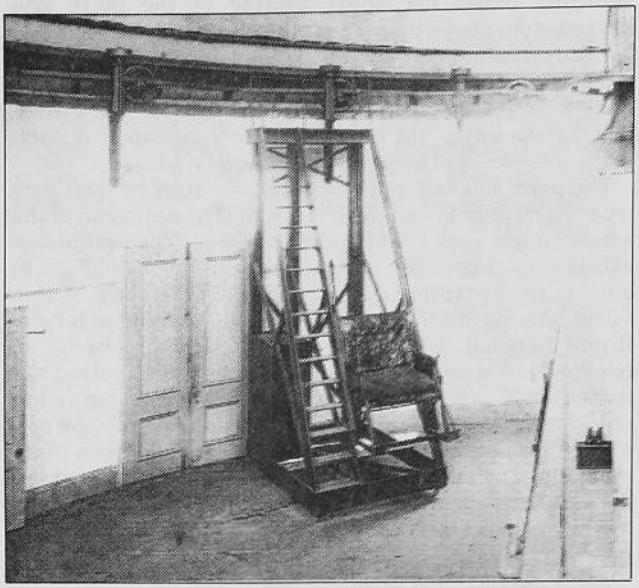
Shutters

After trial and experiments upon various systems of shutters for closing the observing-slit, which is 6.5 feet wide and 39.5 feet long, the following very simple device was chosen, which after a year's trial has shown itself to be satisfactory and convenient. A piece of canvas, 43 feet long and 9 feet 4 inches wide, is used for the covering; to make it water-tight it is treated with two or three coats of linseed-oil. One end of the canvas is lashed through eyelets to ring-bolts at the lower extremity of the slit, and the other end is fastened to a cross-bar of 1-inch round iron, which has a grooved wheel, 4 inches in diameter, at each end. These grooved wheels rest upon brass railway-tracks, laid on the outside of each of the main arches which limit the slit, and travel up and down upon these tracks as the cross-bar is raised or lowered. In the longer sides of the canvas, galvanized-iron rings are inserted every 3 or 4 feet, and these rings embrace two arches composed of stiff galvanized-iron pipes, 2 inches in diameter, which are bent to a circle of a radius 3 or 4 inches greater than the outside radius of the sphere of the dome. The ends of these pipes are secured by passing them through oak blocks bolted firmly to the outside of the dome. To the iron cross-bar, at the upper end of the canvas, two wire ropes are attached, each of which runs from its end of the cross-bar through a series of nicely-fitted brass guideblocks or *fair-leaders*, eight in number, fastened to the faces of the main arches, up to the outside of the dome and to a cast-iron wheel, 1 foot in diameter; returning, the rope passes round this wheel and through a second series of guide-blocks, immediately below the first, and round a second iron wheel, of the same size as that at the top of the slit, at the end of a horizontal axle placed at the bottom of the slit and inside of the dome, and from thence back to the other side of the cross-bar to the point where it is first fastened. It is thus, practically, an endless rope.

Motion can be given to the horizontal axle, at the bottom of the slit, by a simple mechanical arrangement. This motion is at once communicated to the iron bar at the upper end of the canvas through the wire ropes, and the slit is opened or closed with ease. The office of the 2-inch galvanized-iron arches on the outside of the dome is to confine the sides of the canvas by means of the rings which slip upon them, so as to prevent flapping of the canvas in case of high winds, and to keep its edge so close to the dome that rain may not beat in under it. The railway-tracks direct the motion and lessen friction. Simple mechanical arrangements are provided for lengthening or shortening the wire ropes, and for causing the direction of the pull of these ropes to be exerted upon the iron cross-bar in the most advantageous way. This shutter can be opened or closed in two minutes by one man, and it is perfectly water-tight, the canvas requiring renewal about once a year. In a more northern latitude snow might seriously interfere with its efficiency. During the winter of 1874-75 at Washington, however, no trouble was experienced from this cause.

Observing-Chairs

The large observing-chair and step-ladder is of the simplest and lightest construction, and may be understood by an examination of the photograph. It is not placed upon a track, as it serves as a step-ladder as well as a chair, and moves upon the solid floor of the dome on ordinary casters. The chair itself is over-counterpoised, and will move upward by the application of a slight force and downward when the observer is seated in it. To adjust it to any position of the telescope, it is moved slightly above the proper place, the observer enters it, and as it moves slowly downward he fixes it in position by the motion of a lever which interposes a stop in a toothed track. The lower portion of the frame-work carries a closet in which are placed a Ruhmkorff coil and a battery.



This chair is not available for observations near the zenith. For these an ordinary "invalid-chair" is provided, which serves for all observations from the zenith southward to 75° of north polar distance, at which point the larger chair becomes available.

The Mounting

At its foundation the pier which supports the telescope is divided into four parts, each 5 feet by 3 feet, the longer sides being north and south. These are set so as to leave an opening 14 feet long from north to south and 3 feet 10 inches wide from east to west. The opening in the shorter direction is arched over at a height of 8 feet above the floor of the cellar, and the longer opening, running north and south, at a height of 12 feet. The latter arch is built of brick, as is also the pier above it. At the level of the floor of the dome the brick pier is nearly 11 feet long from north to south, and 4 feet from east to west. It tapers slightly on each side to the top. It is surmounted by a stone cap 2 feet by 2 feet by 8 feet, on which rests the cast-iron support (which we call hereafter "the harp-shaped piece") of the telescope. Above the floor of the dome and within the brick pier is a closet, whose floor is covered by an iron base (for the support of the driving-clock) about 3 feet square, the inside height of the closet being about 5.5 feet. This closet is closed by two doors on its east and west sides, and the driving-clock is thus thoroughly protected from dust, etc. The cap-stone is secured to the brick pier by four solid iron rods which pass completely through the base of the harp-shaped piece and through the cap-stone, and are secured by nuts inside the brick pier and above the base of the casing. The southeast rod runs from the nut at the top of the base of the casting downward to the hole in the brick pier, in which the under nut is secured. This hole is printed quite dark in the accompanying photograph. These four rods make the brick pier, the cap-stone, and the harp-shaped piece one connected system.

The Harp-Shaped Piece

The harp-shaped piece, while it is strongly connected with the cap-stone and pier, is yet capable of three motions: one in azimuth; one a rocking motion in zenith-distance, about a north and south line; and one a rocking motion in zenith-distance, about an east and west line. Before the harp-shaped piece was mounted, two pieces of cast iron were firmly bolted to the top of the cap-stone 5 feet 5 inches apart. These serve simply for four horizontal screws to abut against, by whose motion the whole instrument is slewed in azimuth. The head of the southeast screw is just below the crank for rapid motion in right-ascension, and the head of the northeast screw being

vertically under the upper bearing of the polar axis. Immediately above these screw-heads are the heads of two vertical screws which, with two other similar screws on the west side of the pier, serve to give to the mounting the two motions in zenith-distance just described. It has been found that the stability of the mounting leaves little to be desired.

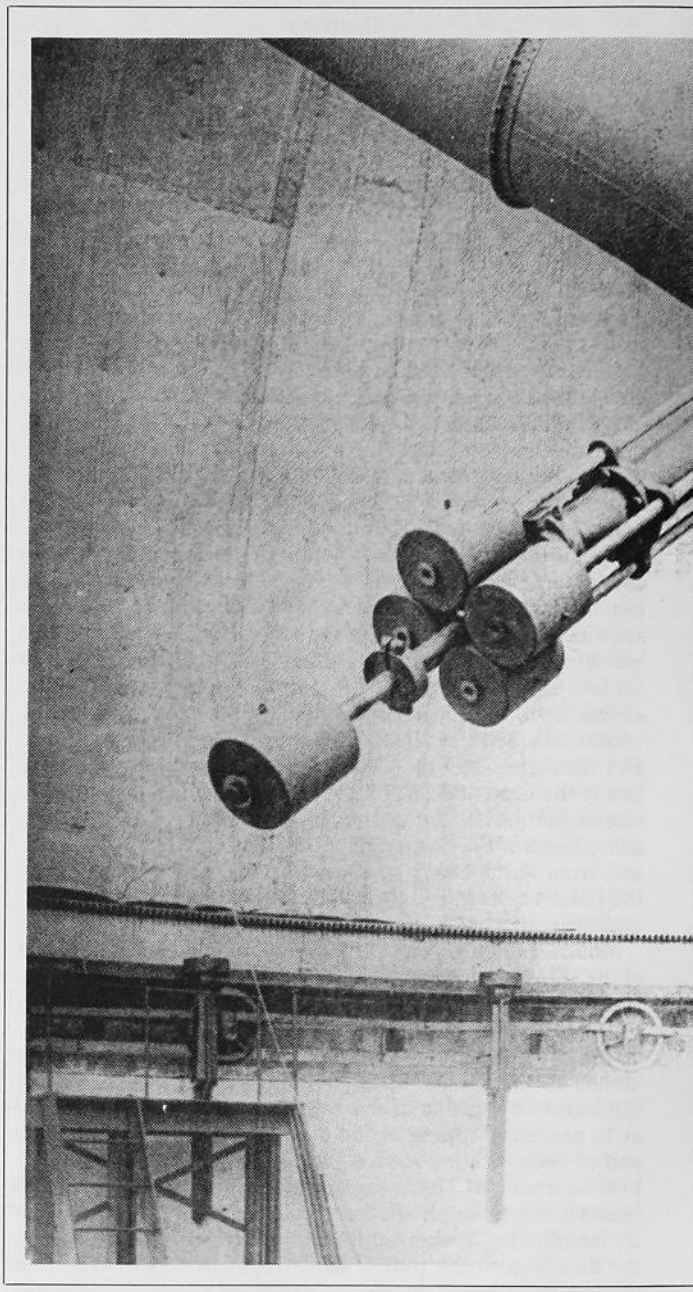
The Axes and Circles

The polar axis is 7 inches in diameter at its thickest part, tapering slightly toward its lower end. The north end of this axis is 19 feet above the floor of the dome. The declination-axis is of the same size, and is pierced through its length by a cylindrical opening, about 2 inches in diameter. A steel flexure-bar passes through this opening, one end of it being firmly fastened to a frame-work inside the tube of the telescope, as near to the cone of rays as it was judged safe to place it. This bar attains the greatest diameter about a foot outside the telescope-tube, where it accurately fills the bore of the declination-axis. It then tapers gradually toward the outer end, the amount of the taper being so calculated that the weight which the bar carries at this end shall be somewhat less than is necessary to make the rod touch the side of the bore.

Friction-Rollers and Counterpoises — The north end of the polar axis rolls in a brass box and is supported by two friction-rollers of steel, about 7 inches in diameter. The weight of the axis is taken from the box by means of a strong steel spring, several feet in length, shown in the photograph, just under the polar axis and to the south of the harp-shaped piece. The lower end of this is perforated, and traversed by a bolt, whose north end is fixed to the casting and whose south end has a screw-thread cut upon it. A nut on the screw-thread confines this spring in any required position. For the declination-axis there are no friction-rollers. The counterpoises, composed of four heavy iron cylinders, are so disposed that the center of gravity may fall within the upper box of the polar axis.

The Circles — The *hour-circle* is divided on its southern face to one minute of time, and is read by two microscopes marked E. and W. (east and west) to one second of time. These microscopes are reached by means of wooden steps, permanently attached to the south end of the pier. There is also a coarse division on the edge of the circle in black and white paint, which can be read from the floor by the unassisted eye to one minute of time, and by means of this latter division the telescope can be set for any object which can be recognized in the finder. The *declination-circle* is close to the telescope-tube, and can be read by two opposite verniers to 0.2 of one minute of arc. These verniers are read from the eye-end of the telescope through two long microscopes, into which the images of the divisions of the circle and of the vernier are reflected by means of two right-angled prisms of glass fixed to the tube. The declination-circle is also divided coarsely on its edge to one degree of polar distance, and can be set by means of an opera-glass to one-half of one degree. For many purposes these coarse divisions of the two circles are the only ones which are needed.

Both the fine and coarse divisions of each circle can be read in the day-time with ease by means of the east microscope of the hour-circle and both microscopes of the declination-circle, as well as one prism and the index for the coarse divisions. At night the coarse divisions of both circles can be made visible by lighting one or two of the gas-burners of the dome. To read the fine divisions of the hour-circle oil hand-lamps must be placed on stands fitted for this purpose. For illuminating the fine divisions of the declination-circle, it was originally intended to use Geissler tubes, driven by a Ruhmkorff coil, and this method was given a thorough trial. It was found that while enough light could be thrown on the circle, the management of the coil and battery was far too annoying, and the very simple device was resorted to of running a gas-pipe up the north end of the harp-shaped piece,

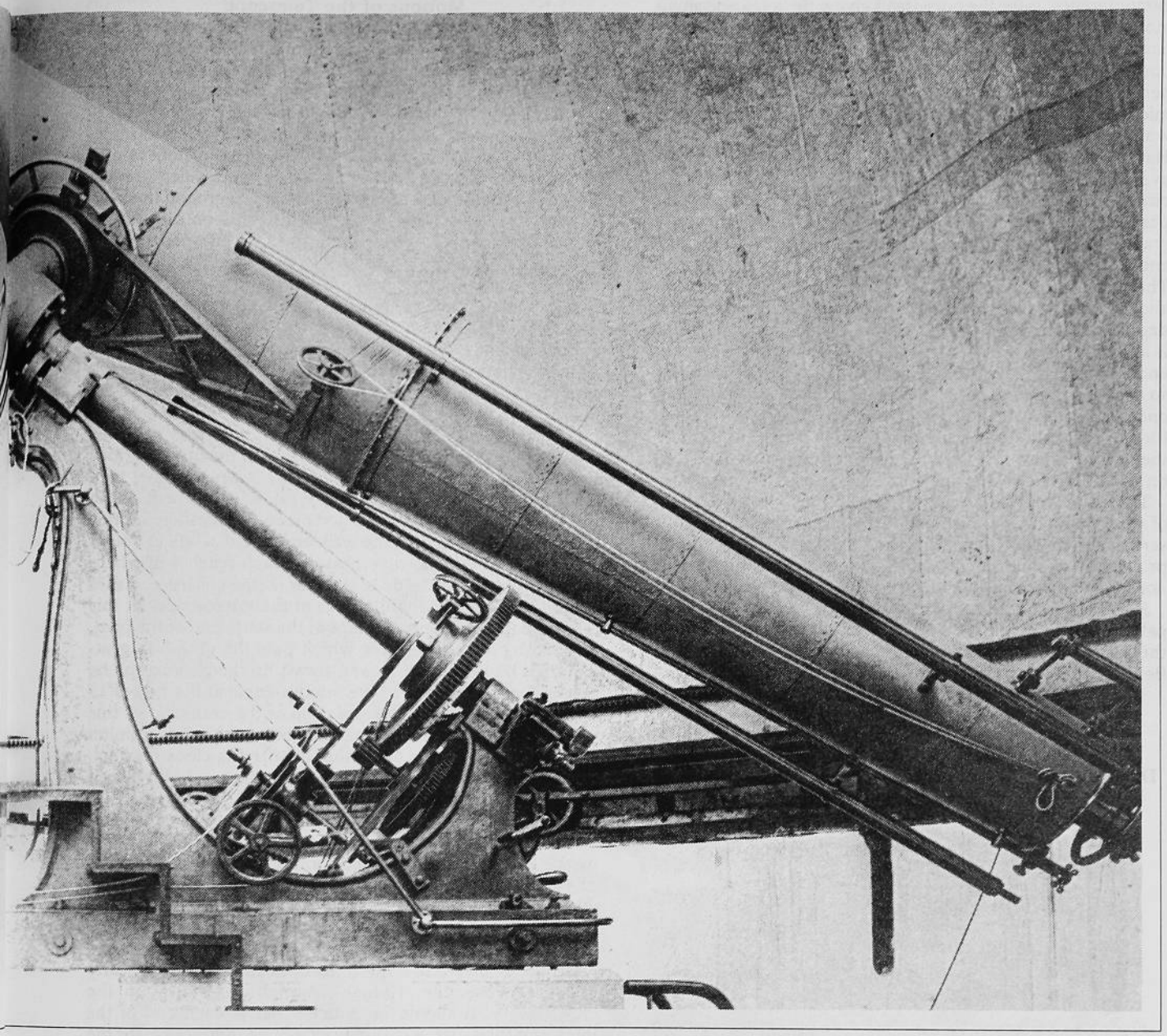


at the end of which two stop-cocks were fitted, to which were attached flexible-rubber tubes terminating in gas-lamps convenient to hold in the hand. A set of steps was put on the east side of the casting, and a small platform which does not in any way interfere with the moving of the instrument nor with its stability, was fixed to the north end. To set the circle the instrument is brought into the meridian and set by means of the coarse divisions to within less than one degree of north polar distance of the required position, an assistant mounts upon the platform and holds the gas-lamp near the vernier, and the fine setting is accomplished by the observer seated in the observing-chair, the declination-clamp and slow-motion screw being convenient to his hand.

This method is perfectly satisfactory, and does away with all the annoyance inseparable from complicated devices.

The Telescope

Tube — The tube is of steel, $\frac{1}{16}$ of an inch in thickness near the ends and $\frac{1}{8}$ in the middle, and is made in three sections. It is about 32 feet in length, the middle one-third being about 31 inches in diameter. From this middle one-third the tube



gradually tapers to about 28 inches at the object-end and 21 inches at the eye-end. This latter is closed by a brass plate, into which the sliding-tubes for holding the position-circle, eye-pieces, etc., fit. At the object-end of the tube are two iron doors, about 4 inches square, which can be removed for ventilating the tube. Such experiments as have been made indicate that the difference of temperature of the air outside and inside the tube is usually not greater than 1° Fahrenheit. One of the ventilators is close to the cell of the object-glass.

Object-glass — The object-glass is composed of an equi-convex front lens of crown-glass and a nearly plano-concave flint lens, the clear aperture being 26 English inches, and the principal focal distance of the combination being 390 inches, nearly. The radii of the three curved surfaces are each about 161 inches. The thickness of the objective at the center is about 2.87 inches. It is confined in a gun-metal cell which has adjusting-screws for collimation, etc. The objective cannot be rotated in its cell.

The glasses are free from all hurtful rings and striae, and are of nearly perfect figure. To test their figure, the telescope, with the full aperture of 26 inches, was pointed upon *Uranus* March 10, 1874, and the eye-piece, magnifying 600 diameters, was carefully focused on the two satellites *Oberon* and *Titania*. The central portion of the object-glass was then stopped out by a cylindrical stop of pasteboard, 20 inches in diameter, placed approximately central over the object-glass, and the telescope again directed upon the satellites. These were seen with the same focus perfectly sharp and well defined. The series of measures of very close double stars in 1874 and 1875, by Professor Newcomb, and in 1875 and 1876, by Professor Hall, show also its superior defining power. The light of the telescope, as well as its defining power, may be judged of by the long series of observations of the satellite of *Neptune* and of all four satellites of *Uranus* in 1873, 1874, 1875, and 1876, by the forty observations of *Hyperion* in 1875, and by the discovery of three minute and close companions to *Procyon*.

The Position-Circle and Micrometer — When it is pointed to the zenith the eye-piece is about 3 feet above the floor of the dome. The large wheel with metal spokes and a wooden

circumference, is for the purpose of giving the telescope small motions in right ascension and north polar distance with the hand, and has been found to be very convenient. The position-circle screws into the first sliding tube and remains permanently attached to the telescope, whether the micrometer, spectroscope, or a plain eye-piece is used, in the way proposed by the late Professor Winlock, director of Harvard College Observatory. The micrometers, the plain eye-pieces, etc., fit into a slipping tube beyond the position-circle, and are fixed in position by a clamp-screw. The position-circle is about 8 inches in diameter, and has two graduations: The first (coarse graduation) is on its outer face, and is to single degrees. This is read by an "index" or pointer. The second (fine graduation) is to two-tenths of one degree, and is read by two verniers to one one-hundredth of one degree. Reading-glasses are fitted to these verniers. The index is about 90° in angular position from each vernier. A clamp and tangent-screw is fixed to a collar which can be clamped so as to bring the clamp to any position on the limb. When once clamped it cannot be moved without altering the reading for the parallel or zero of position. Four complete turns of the tangent-screw will move the zero of the vernier over 1° on the limb of the position-circle.

There are three micrometers, on primarily for measures of position-angle and distance of faint objects, (although it serves equally well for such measures of any objects) one principally for determining differences of right ascension and north polar distance, and one Airy double-image micrometer.

Eyepieces — There are four negative eyepieces, of the Airy pattern, which fit into the slipping tube of the telescope when the micrometer is removed. Their magnifying powers and fields of view are as below.

Negative Eyepieces

Designation	Magnifying Power *Diameters*	Field of View ′	Makers
AI	155*	25.2	Clark & Sons
AII	439*	10.5	"
AIII	863*	3.5	"
AIIII	1,360*	2.5	"

*Approximate

Finders — There are two finders, one by Clark & Sons, 5 inches in aperture, 72.5 inches focal length, with two eye-pieces. The one usually used has a field of view of 1° 18′, and a magnifying power of about 30 diameters. The other has a magnifying power of about 75 diameters. The second finder, by Kahler, is situated 90° in position-angle from the first, and has an aperture of 2⅛ inches, a focal length of 21 inches, and carries an eye-piece magnifying about 12 diameters, and having a field of view of over 3°. This finder is quite convenient for use when the larger one is either too high or too low for ready access. Both these instruments are very carefully made. One photograph shows the small finder above the tube, the 5-inch finder being on the west side, and not shown; the other shows the eye end of the 5-inch finder and the whole of the small finder.

Spectroscope — The instrument is provided with a star spectroscope of two 60° prisms, made, after designs by Professor Newcomb, by Clark & Sons. It has three eye-pieces.

Dynameter — A Ramsden dynameter has been made for use with the telescope by Mr. Edward Kahler.

Clock — A siderial clock is mounted on the east side of the dome, and connected electrically with the chronograph.

Motions of the Telescope

The telescope being mounted on the German plan, has motion about two axes perpendicular to each other. Arrangements are provided for securing —

(a) A slow motion in North Polar Distance
(b) A rapid motion in Right Ascension
(c) A slow motion in Right Ascension

Clamping in north polar distance is done by means of a long, stiff brass rod. The slow motion in north polar distance is given by means of an endless rope passing around the head of a large wheel at the end of the slow-motion screw. The whole of this rope extends from near the eye-piece to the wheel.

The device for securing rapid motion of the telescope in right ascension consists essentially in a large cast-iron toothed wheel, having 96 teeth (one tooth to each fifteen minutes of right ascension) which is clamped firmly to the polar axis just above the hour-circle. Immediately below this wheel, a small iron pinion turns on an axis parallel to the polar axis of the instrument. By the motion of a lever on the west side of the pier (not shown in the photograph), this pinion may be raised or lowered so as to be in or out of gear with the first-described wheel. This pinion is connected by a small train to a horizontal axle running east and west, which is fastened to the south end of the harp-shaped piece. The east end of this axle carries a crank, and the west end carries a wheel, round whose rim an endless rope passes, which reaches nearly to the floor on the west side of the pier. If the observer wishes to set the hour-circle while he is at the microscopes of this circle (i.e., standing on the steps at the south end of the pier), he first depresses the lever which puts the pinion in gear, and then by turning the crank shown in the photograph he causes the telescope to move in hour-angle at the rate of 15 minutes of time for each revolution of the crank. After this setting is completed the lever must be raised and the pinion thrown out of gear, in order that the driving-clock may act. More usually the rapid motion in right ascension is required in setting the telescope from the floor of the dome on the west side of the pier. The observer can depress or raise the lever for throwing the pinion in or out of gear from the floor by means of two ropes, and the motion in right ascension is effected by a pull upon the rope encircling the rim of the small wheel which is at the west end of the same axis which carries the crank.

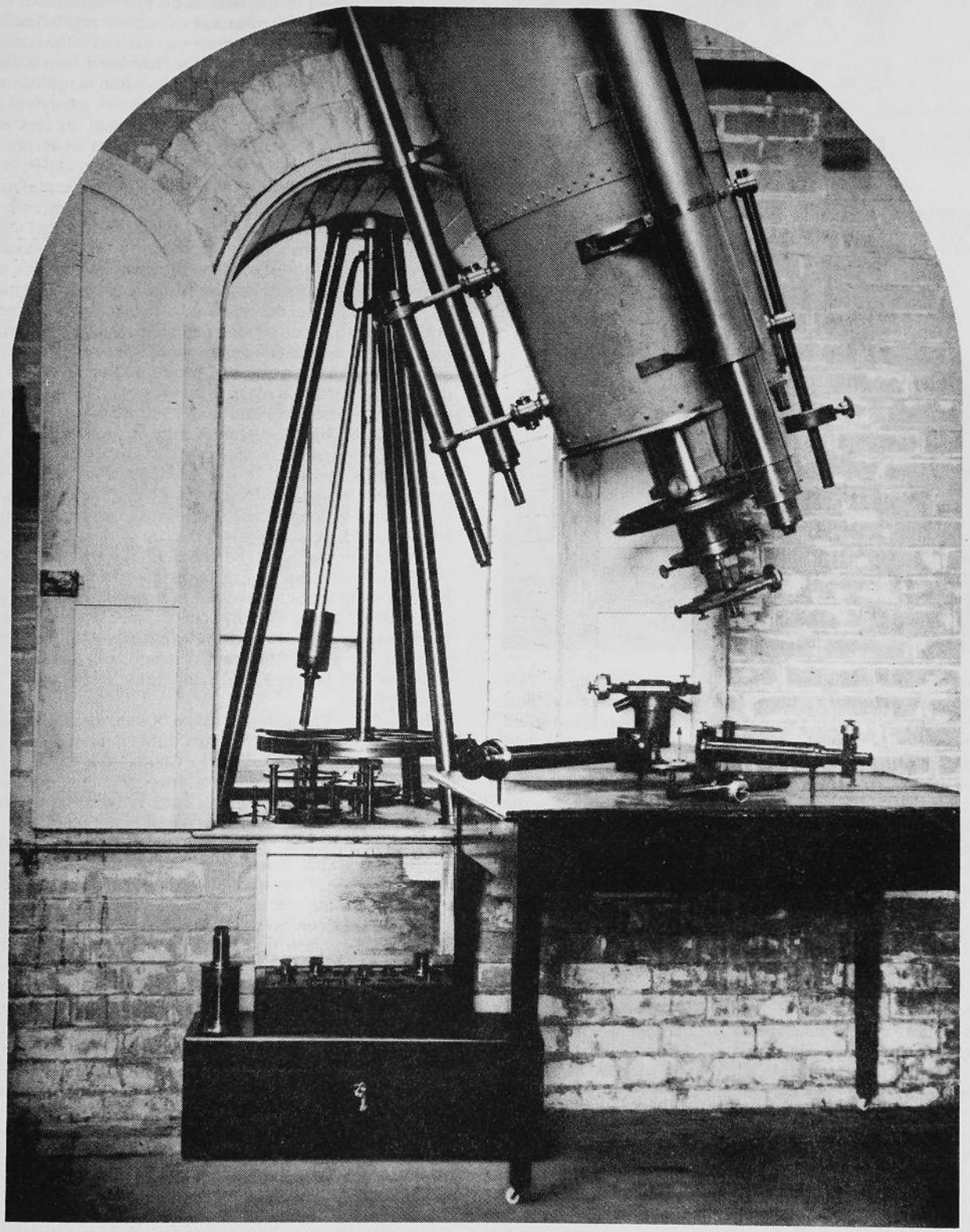
This whole apparatus is simple and, at the same time, effective; by means of it this telescope can be reversed nearly as quickly as the 10-inch Munich telescope of the Observatory. It should be noticed that to each end of the telescope-tube a stout cotton braided line is attached, for the purpose of aiding in maneuvering the telescope. Some portion of this is always within reach from the floor of the dome.

The clamping in right ascension is done by means of a rope on the northwest corner of the pier, which passes round the head of a wheel between the polar axis and the telescope and close to the large wheel for rapid motion in right ascension. The slow motion in right ascension is secured by turning a wheel, shown in the photograph directly in the middle of the harp-shaped piece, and on its east side. The endless rope for giving this motion passes the northeast corner of the pier.

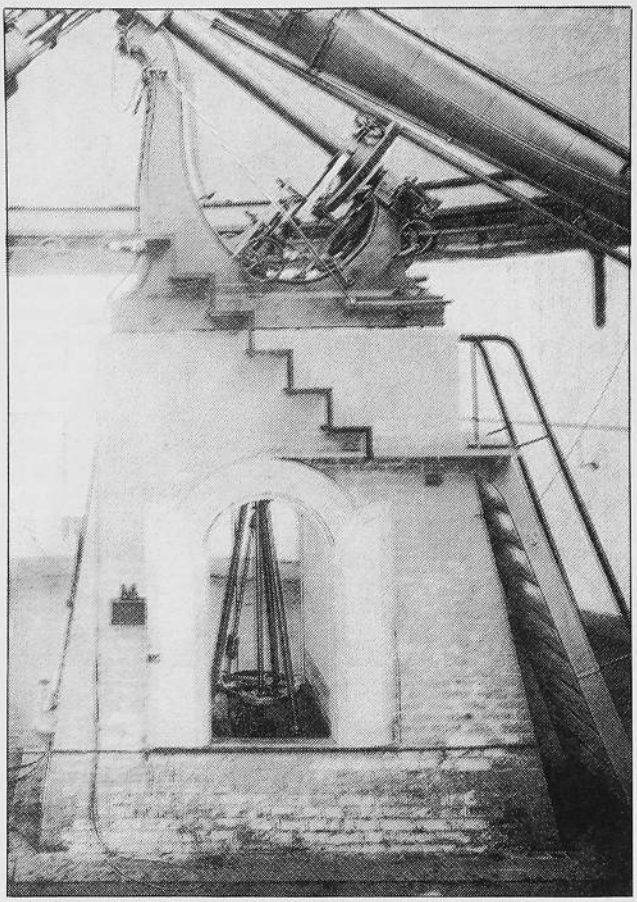
The Driving-Clock

The form of driving-clock adopted is the invention of Professor Newcomb, and was devised by him with special reference to the xxvi-inch equatorial.

It will be convenient to describe first that portion which is for the purpose of giving the requisite motion to the train, and second the portion whose office it is to regulate the motion and to make it sensibly uniform. The driving part is mainly situated in the cellar beneath the dome. It consists, first, of a small reaction water-wheel (the "Barker's Mill"),



DETAILS OF CLOCK-WORK, ETC., OF XXVI-INCH EQUATORIAL.



which is moved by water from the city water-pipes. This water may be turned on from the dome by means of a vertical rod at the north end of the pier. When the water is so turned on the reaction-wheel begins to revolve, and causes a weight in the cellar to ascend. When this weight has reached a certain point the water-supply is automatically shut off, and the reaction-wheel wholly or partially ceases to turn, while the weight falls. While the first weight is falling a weight of about one-fourth or one-fifth the weight of the first is forced to ascend, and just before the first weight reaches its lowest point the water-supply is again automatically turned on and the first weight is again raised. The connection between these weights, by which one is made to rise when the other falls, and by which both weights are connected with the driving-clock and the vertical axis of the water-wheel, is that of the well-known Huyghens' loop. The cord which forms this loop is endless and passes around four wheels, two horizontal and two vertical, a small guide-pulleys being introduced to change direction. It first passes round a horizontal wheel on the vertical shaft of the water-wheel, from thence round a vertical wheel above and attached to the heavier driving-weight, thence round a horizontal wheel which is fixed to the vertical shaft of the driving-clock (in the closet of the pier above the floor of the dome), and from thence to the vertical wheel of the lighter weight, and finally back to the point of beginning. About 90 foot-pounds per minute is required to drive the clock in its present form, but by far the largest part of this is expended in overcoming friction in the apparatus beneath the floor of the dome.

This rope passes round the bottom of the vertical shaft of the clock just below the first toothed wheel of the train. In this way the driving-weight gives approximately uniform motion to the first wheel of the train, and from this first wheel the motion is transmitted through the wheels of the train to a vertical rod on the west side of the pier, at the top of which is the beveled wheel through which the motion is transmitted to the sector, etc.

The first wheel of the train is on the vertical axis of the conical pendulum, by means of which the regulation of the motion is obtained. On this same vertical axis is the horizontal wheel round which a portion of the Huyghens' loop is wound, and also a heavy fly-wheel. The pendulum is of the conical description and makes one revolution in two seconds of time. To insure isochronism, the horizontal axis of the fork which supports the upper end of the pendulum does not pass through the center of the vertical shaft, but beyond it, at such a distance that the average inclination of the pendulum-rod corresponds to the minimum velocity of the axis. The pendulum is constrained to move nearly in a circle, but it has a slight play in a direction radial to the horizontal fly-wheel, and this play takes place in a small narrow slot, about three-quarters of an inch in length, inside of which the narrow lower end of the pendulum moves. The pendulum in moving outward in this slot pushes before it an insulated strip of platinum to which a copper wire is attached, which is connected with one pole of an electro-magnet. The wire from the other pole of this magnet is connected, through contact springs, etc., with the pendulum itself, so that so long as the pendulum touches the platinum strip, i.e., so long as the clock is running too fast, the electro-magnet is in action, and attracts its armature to itself. To the armature is attached a small brake or friction-pad which plays against the rim of the fly-wheel, and so long as the electro-magnet is in action, the friction-pad is pressed against the rim of the fly-wheel, thus retarding the motion. The moment the pendulum drops within its proper limit the brake is released from action. The brake is set in action several times for each revolution when the clock is running well. By constant care this form of clock-work may be made to perform extremely well, but neglect of oiling for a few days causes irregularity of going. This constant care is given to it and it has usually given good satisfaction.

The Sector — The general method of transmitting the motion of the clock-work to the polar axis through the sector is similar to that usually employed by the Clarks. The sector will run for more than two hours continuously, and a means is provided for quickly setting it back to its first position.

Chronograph

The chronograph is peculiar only in the method of regulation, which is a simple modification of the system adopted in the driving-clock. Its conical pendulum makes one revolution in one second, and it is suspended on its vertical axis just as the conical pendulum of the driving-clock of the Equatorial. To insure accurate circularity in its path, the following simple device is used: on the vertical axis of the pendulum, and below this, is placed a ring with three arms. This ring slips around on the axis, a very slight force serving to move it. The three arms are horizontal, and at an angular distance of 120° apart. The outer end of each of these light arms is bent upward, so that, seen sidewise, the arm looks somewhat like an ordinary fish-hook, with the point turned in toward the pendulum-axis. The length of these arms is so regulated that when the pendulum is moving in its proper circular orbit the lower end of it just swings inside of the points of the arms. If, from any cause, the pendulum begins to move in an ellipse (and hence not uniformly), it cannot move more than 120° (that is, not longer than one-third of a second) without touching one of the three arms as it swings outward. This arm will now be carried round in front of the pendulum (carrying the ring and other arms with it) until the pendulum drops inside the arm, and the whole process is repeated. For a fixed observatory this form of Chronograph is perhaps as convenient as any other, and the regularity of the motion of the barrel leaves nothing to be desired. ■

DOBSON on Dobsonians

A paper given at the Riverside Telescope Makers Conference, 1983

Since I am to talk on Dobsonians, I have to make my old complaint. Long before they were called Dobsonians, I used to complain that telescopes should not be called by people's names. We used to say, "Maksutov, Schmaksutov; Cassegrain, Schmassegrain; Schmidt, Schmidt." Now it's Dobsonian, Schmobsonian.

Before I start talking about telescopes, I should tell you something about the Sidewalk Astronomers. We wanted to go to Canada this summer. There's a lady there who runs a roving planetarium through Alberta, and when we were there with our telescopes last summer, she met us at Banff and invited us to come this summer. But they couldn't get it funded in time.

Jim Jacobson, of Coulter Optical Company, has been kind enough to donate two Odyssey I's and they've already been shipped to Chicago. Chicago will get them to India, and we'll be in India for about four months. There we will not be running short of eyes, so we wanted telescopes to which you can quickly walk up and quickly walk away. There's no way that we want a twenty-four inch telescope with a twelve foot ladder in the night!

But, as of now, this summer's tour is cancelled unless we suddenly get some donations which we're not expecting. We've postponed it till fall. But the Canadian people expect to get us funded to go to Alberta next summer. They said that it has been approved in principle, and in their country, that's the important thing. If they've approved it in principle, they'll find the cash.

I think most of you know the Sidewalk Astronomers and what we do. There's a Sun telescope just out there, and in front of it there's some literature about us, including some diagrams of the Sun telescope. Those of you who are interested in making a Sun telescope, please help yourselves.

When Richard Berry heard that I was coming down to talk on Dobsonians, he asked me if I would please send him the text of my talk so that he could get it into some kind of anniversary issue of TELESCOPE MAKING magazine, so I had to write back that there were pictures, too. They *are* pictures that were long, long ago designed to go in a book called *Sidewalk Telescopes*.

That's what we were going to call our book.

Meanwhile we've been scooped by Richard Berry, and there's already a book on *How to Build a Dobsonian Telescope*. I've already propositioned him so that if he wants, in a future issue, he could get all these pictures, along with our comments. We wanted a telescope book with pictures clear enough so that someone who couldn't read could get the job done. We also wanted the text clear enough so a blind person could get the job done, so it could be translated into Braille.

Those of you who think that these pictures ought to be published can bug Richard Berry. He might get them published. We're probably not ever going to get our own book on telescope making out because it is no longer necessary. Somebody else has already done the job, but I've been working on it for the last fifteen years. A lot of the text was already written fifteen years ago — some of you were just little kids then. I've been old a long time.

Anyway, I should tell you how those pictures were made. I went down to Palo Alto, and one of our hard-core Sidewalk Astronomers, Molly Lusignan, got out her camera and, right in front of her camera, I put together the front end and the back end of one of these telescopes. Then, over a five year period, the pictures have been made into line drawings by Earl Junghans so that they could be cheaply published in the book. Meanwhile the book's been published by Richard Berry.

Let's start the slides.

Here we are measuring the tube. It's a 10-inch tube for an 8½-inch mirror. Here we're peeling out the plastic from inside the tube. It comes out easily.

Here we're peeling off the outside layer of waxy paper. It comes off with difficulty, but if you leave it on, you run a hose over your telescope and get off scot-free.

This is the diagonal mirror block. We put shingles into these slots, and put the mirror on the 45° cut mounted on three blocks of leather about half an inch on a side. It's held with white glue. If you're not independently poor, like we are, you can use silicone rubber. If you do, put three blobs on there and let them set up. Then put blobs on top of your blobs, and put your mirror down.

Here we're cutting the shingles to go into the block. We don't glue the shingles into the block because what happens to them is that some kid, with ice cream on his hands, reaches into the front end and breaks them off. Now if you have them glued in, you need a table saw to re-cut your grooves. If not, you can pick the pieces out of the grooves with a nail, put in another shingle, and you're back in business. Our telescopes are made of crude materials, and the repair tools are also crude.

Here we're going to measure the distance from the center of the block out to where the shingles get cut off. You put your compass at the center of the block and put those little lines out there and saw the shingles off. We're sawing them off with a hack saw. Then we'll cut the corners off; otherwise when you slide them into the tube, the shingles tend to split.

Years ago, when I lived in a monastery up in Sacramento, I had to make these things on a shoestring. It took me several years of selling Green Stamps and Blue Chip Stamps to collect enough money to aluminize our first eighteen incher, which is now called The Little One. In those days we used shingles that were blown off roofs in a storm. We picked them up off the ground, already black from the Sun, so we didn't have to paint them. Now we do it this way, but we still use shingles. If I designed something to hold the spider mount it would be a cedar shingle. Actually we now use shim stock which is already cut an inch and a half wide. If you use shingles, you have to split them.

Here we have the little pads of leather, and we're putting them on with white glue. The mirror's lying down

there. We'll put white glue on the leather, and put the mirror on top of the white glue.

There's the mirror on the block. Now we stand it up on the spider leg that goes away from the direction the mirror faces, and rest the other two legs against something that keeps it level while the glue sets up. See, we lean it against a can. Isn't that jazzy? And if it slips, you put your pliers behind one leg and it keeps it as level as you like.

Here we're beveling the inside of the cardboard tube that the plumbing piece goes in. We put our eyepieces in chrome-plated brass tubing (1½" o.d.) from a wash basin drain line trap. You just go to the plumber, and he has a whole bunch of them in the scrap bin, and if you're a lady, he'll give you a handful. Years ago, up in Sacramento, we used to make twelve inchers out of the cores of hose reels. They were 22 inches long, 12 inches inside diameter, about a quarter inch wall, rigid cardboard tubes with big plywood wheels on the ends. I was in the monastery in those days, and I used to go in there and get those tubes. But the kids in Sacramento, a whole lot of them, took to making telescopes and we needed a whole lot of those things; so I turned the job of getting them over to the mother of one of those kids, and she went down with a pan of brownies and she got a whole lot of tubes. But after that they wouldn't give them to me.

So we use this chrome-plated brass tube focuser sliding against cardboard. It's about as smooth a focuser as you can manufacture, and it's cheap. It doesn't cost anything.

Here we're drilling the eyepiece hole. If your tube is as long as your local length, then you measure back from the front end of the tube by the radius of the tube, and cut your eyepiece hole. We're cutting it with a fly cutter, run around backwards, by hand.

[One of the pictures fails to show on the screen.]

Never mind, we've got plenty of pictures. We wanted it so you wouldn't have to read anything. I showed these pictures to some kids in Palo Alto once, then asked them, "Could you make this telescope if you didn't have any text?" and one of those little girls said, "There're a few places where I'd need words."

The eyepiece tube fits through the main tube from inside through the hole. Eventually we'll put glue on the little tube where it fits into the big tube, and one the edges of the masonite where it runs into the wall of the big tube, and that's where it'll stay. But glue doesn't hold these things — eventually they get knocked off on door jams, and when they do, you get out your tube of glue and put it back. Bones are much harder to mend.

I have some funny stories. I might as well tell one while this slide burns. We were here at Riverside in 1978, and we had a twenty-four incher and a twenty-two. Gerard had his twenty-two. It had a focal length as long as the twenty-four but it was a little skinnier, and in those days it was called Long Eye. He took a prize here for "good workmanship," but on the way to the Grand Canyon the tongue of his trailer sheared off and he lost the telescope at 55 mph on the freeway, and it crashed into a post.

Gerard was fit to tie.

He said he wasn't even going back to pick up the garbage. But one of the other Sidewalk Astronomers and I persuaded him that we'd have to go back and get that stuff, and in two days we had it back on the sky. In two days, with government plywood, we rebuilt it and put it back on the sky. Then it was called The Phoenix because it arose from its own ashes.

Here we're painting the inside. Only the region visible through the eyepiece tube needs to be painted, and it needn't be black. I said in my classes for years, "It doesn't need to be black, only dark. You can put murals down the inside." Finally somebody did it. They put planets and things all down the inside in a deep blue sky.

Here we're putting in the diagonal mirror. The parts of the diagonal mount that face the eyepiece tube should be dark.

I'm cutting a piece of cardboard to put under the back leg so the spider will be tight. Match boxes are okay: those things you carry in your pocket to light up "the Red Man's Revenge." The back leg goes away from the eyepiece tube so that, in the final adjustment of the diagonal, we can move the back bar wherever we want the image of the objective to go as seen through the eyepiece tube.

Here we're gluing in the eyepiece tube. We do this only after we get our mirror aluminized and after we get our optics all lined up. This isn't a real telescope. This is just to show you how to do it.

Here we're putting the 7x50 binocular eyepiece into the brass tube. I think I should tell you another funny story. About twelve years ago I bought a few hundred of these eyepieces from a man in Seattle at about $4.50 apiece, and resold them for $5.00 apiece, and we had eyepieces for quite a long time. I still have two or three to replace the eyepieces in the twenty-four and so forth, just two or three. But I found out from the man who sold them to me that he had sold several thousand to Edmund Scientific Company for 75 cents apiece — where they went on sale for $6.75. Then it went up to $9.75. The 75 cents has always been in there!

When we put the eyepiece into the tube, we take off the eye cup. Now the reason that we take off the eye cup, and the reason that we Sidewalk Astronomers use long focal length optics and long focal length eyepieces, is that we are astronomical entertainers by appointment to her majesty the American public, and she has to get in there and look with her eyeglasses on. And if you have a half-inch focal length eyepiece, or one of those quarter-inch jobs which are like tear immersion lenses, you cannot get her in there without refocusing it for her, and that cuts down on the number of people across the eyepiece from one or two thousand to about a hundred.

At Ghirardelli Square we often get a thousand people a night, sometimes two thousand. In the national parks, we get something like three to four hundred people per night. At the Grand Canyon one time, the rangers asked us to keep tabs on it, and it turned out that in sixteen days and nights we entertained 20,000 visitors. We had Sun telescopes in the daytime, slide shows in the evening, and six or eight telescopes at night.

I'll tell you another story. One time at the Grand Canyon I had a Sun telescope, like the one out there, and I asked a well-dressed man in a business suit if he wanted to look through it. After he had looked, I said, "Come back this evening; we'll entertain the hell out of you." He stood up to his full height and said, "There is no Hell in us: we are Christians. But we would like to see the works of the Creator."

Here we're cutting the tailgate. For a ten inch tube, we want it eight inches square. Then you draw a ten inch on it and cut off the corners, where the circle crosses, and it just fits into the tube. The corners will be held in tight with sheet metal screws.

Here we're finding the center for our circle. It just hits the corners, so you just have a tiny bit of sawing to do.

Oh, we're back to the first slide. Go back, please, and take it out. I don't usually have all this help. [Ashley McDermott, who had introduced John, was running the projector.] You know, you people down here are very nice to us. [Ashley said, "We like you too."]

Thank you!

Here we're cutting off the little corners.

You see, I wanted you to see everything, so that even a retard can get the job done. Just because you have problems doesn't mean you don't need to see. Everybody has to see. It is stupid to live in this universe and never see it.

To put in the collimating bolts, we draw a six inch circle, divide it into six parts, then put a bolt hole on alternate spots, with one at the top and one on the either side.

We have a pair of twelve-inch binoculars called The Kangaroo. It weighs about 300 pounds and operates with both eyes looking straight at the Moon at 90x. But those bolts are not put in this way. The outside bolts are put on the outside edge, so that you can make it look cross-eyed to see the trees a mile away. It makes the bushes stand out from the mountains at fifteen miles. I looked through both of them at the Moon on the first day the astronauts footprinted it.

Here we're drilling the bolt holes, right through the wood. Then we use a "church key" to wind them in. We want them tight. If the bolts are loose, the kids at the star parties will wind them up tight. Next we glue a thin cardboard triangle to the inside of the tailgate, with three little pads of masonite on the corners, so that the mirror doesn't run into the bolts. If, by accident, you drop your telescope on the concrete tailgate first, you don't want your mirror to run out of the holes like bath salts, so it's cushioned by little pads of masonite glued to the cardboard. You can't glue the masonite to the bolts. It won't stick. This cardboard should be floppy. If it doesn't flop right, put a pencil under there and bend it down till the pads stay flat over the bolts. I don't know much about metal technology, but cardboard and wood I understand.

Now we're putting furring nails at the front ends of the blocks that center the mirror in the tube and keep it from running out the front end. In my telescope making classes, I always say, "Booboo #1 in this class is dropping and breaking your objective, and if you're going to do it, do it at once. Don't wait till it's finished. And booboo #1½ is tipping your front end down, without having furring nails in the blocks, and rolling the mirror out past the diagonal and losing them both."

Our mirrors are thin,so we use three inch blocks and put an ice pick hole in the middle, 1½" from the end. Then we put a screw hole in the tube 2½" from the end. That puts the end of the block one inch inside the end of the tube, and the tailgate butts against it. It should butt against all four blocks. If the tailgate touches only three blocks, you can glue a penny or a piece of cardboard to one of the blocks, or you can use a hammer. I use a hammer. I'm like the man who had five cat holes in his kitchen door. When someone asked, "Can't they all go out through the same hole?", he said, "When I say scram, I mean *scram*."

The mirror is going to rest on two of these blocks, and there will be two at the top with furring nails in them, so that even if you tip your mirror forward it can't roll down the tube. The tailgate will be vertical, with horizontal bottom and top, and we put blocks and tailgate in with #8x¾" sheet metal screws. These bolts have a thread section only one inch long. We want it to be impossible for anyone to wind them up till the mirror touches the furring nails. The nails are not part of the telescope in operation. They are just to prevent booboo #1½.

Some of these slides are not very clear. Sorry about that, but the original pictures are very, very clear.

There's the objective mirror from behind. We can reach our fingers in past the tailgate and turn it to see if it has astigmatism. Also, these holes are used for ventilation. You mustn't keep your telescope in a warm place and then get it out under the cold night sky, or the air currents in the tube will make it impossible for you to read the defects in your mirror.

For lining up our optics, we put a half-inch colored decal at the center of the aluminized objective. We line up the diagonal so that, looking down the eyepiece tube with an extender in it, we see that decal straight down the axis of the eyepiece tube. After that, you fiddle with the tailgate bolts till the decal covers the iris of your eye centered in the eyepiece tube, and seen in the reflection from the objective mirror. There are only two things to line up, and if you do them in the right order, it takes just five minutes.

That's looking into the front end of the eyepiece tube with an aluminized mirror in there. That's what you'd see if your optics are properly lined up. Only then do you glue the singles to the main tube.

This is an out-of-focus diffraction pattern drawn by yours truly. It is just to explain to my classes that when we figure these things at the eyepiece, we choose a bright spot of light, either a star or the glint of sunlight from a power-pole insulator, and then we throw the eyepiece out of focus — too far in and too far out. What we do in figuring is to match the distribution of light in the out-of-focus disks. If the distribution is the same, inside and outside, as seen by you, it might be okay. If it's the same as seen by me, it's okay. That's the end of the slides.

[Ashley asks, "Shall I use the third tray?"]

No,no, I don't think we need to see it. [The audience expresses disappointment.] If you want to see some more, we could show it. The next will be photographs of people making telescopes. Do you want to see them? I was told I wouldn't have much time, so I talked loud, fast, and out of tune.

[Cliff Holmes says, "John, you've got about twenty minutes.]

All right, that's fine.

This is yours truly, about fifteen years ago, before his hair got grey. I'm doing some fine grinding here because I had a mirror to grind on the day that Bruce Sams was grinding his. Bruce is now at Caltech, but in these pictures he's nine years old. He was one of the first three Sidewalk Astronomers, he and Jeff Roloff and I, and he is the person on whose account the Sidewalk Astronomers were founded. His mother called me up and said that "Brucie" needs someone to talk to about telescopes and about astronomy. He'd taken the astronomy course at the Morrison Planetarium twice and needed something more.

This is a posed picture. She wanted me out of the way.

Here we are on a pitch lap in the real world; there is a Bruce Sams. He's now at Caltech and much taller than I. He could pick me up and throw me against the wall. In the real world he did his own work, but his mother wanted pictures of me. When he was thirteen he made an eighteen-incher and won the California State first prize in the Science Fair with his telescope, but he was three years too young to go to the national finals.

Here we're putting in the tailgate. And here we're building the box. This is plywood out of a debris box on the street. The rocker also is discarded plywood from the building of an apartment house. We're recycling junk. In our mirrors we're recycling the Navy, and a lot of this other stuff is recycled junk.

Here he's testing his focal length by shining the reflected beam on his brother's tummy. That's not a smart idea. Don't do that to your brother! There's only a four percent reflection, and it's not very dangerous, but if it got in his eye it might be damaging.

When he had finished this 10½-incher, he was my assistant at the Jewish Community Center, but he was so small they wouldn't listen to what he said, so I gave them a tongue lashing.

That's one I built in Sacramento long ago. It's made of those old hose reels. This is a "four-barrel-twelve." There are four 22" pieces in there. It's still one of our workhorses, called Stellatrope. Its companion was called Heliotrope and now lives in California. I had to sell it for diagonal mirror glass.

I do sloppy work, but some of my friends save my reputation. See, he even upholsters the rear end. Here's another kid making a 10½-incher and grinning

from ear to ear.

Now you see, we do not have grinding and polishing pictures for the Sidewalk Astronomers' telescope book. Also, in *How to Build a Dobsonian Telescope*, there is no information on grinding, polishing and figuring. It all ought to be in the same book. It's unfair to have it the way it is. I think it should be edited with these telescope building pictures in there, and with some pictures showing how the grinding and polishing are done, and how the figuring is done if you want to read your mirror at the eyepiece on stars or power-pole insulators.

Here he's drilling the holes through his tailgate, and here he's catching the reflection of the Sun to measure his focal length.

And here he's being regurgitated by the tube.

Here he's making the eyepiece hole, and the next slides are of someone else.

I want you to watch this six-incher and see what happens.

Now it's a twelve-incher. Fred Dilts made a six-incher and a twelve-incher, and he painted them just alike. They're painted with seven coats of marine enamel. Don't ever do it. I have argued for years that there is no earthly reason why telescopes should be white outside. The problem is how they handle infrared, not how they handle sunlight. They're not used in the daytime, so that has never been a problem. What you need to find out is what paint to use for the infrared, and it's not marine enamel. This telescope will dew down one hour after sundown on a night when no other telescope will dew down. I've been at the Lawrence Hall of Science in Berkeley on a sunny day when the Sun was coming straight down on the back of it, and the belly of the tube was warmer than the top. The top can handle the sunlight, but the belly can't handle the infrared radiated up from the sidewalk.

This is some side bearing detail. We use wooden disks, wrap sheet metal around them, overlap the ends and drill holes through them. Then we drive a screw through the holes and into the notch in the disk till it pulls the sheet metal tight over the shoulders. The metal runs on Teflon. All our telescopes run on Teflon.

That's the Giraffe. It was built by a sixth grader in the 60s. It shows six stars in the Trapezium, and is still one of our workhorses.

This is a nine-incher. The father of the girl who made it traded catfish for the aluminum side bearings. It belonged to a fifteen-year-old girl named Mo, and when we were figuring her mirrror, it looked real good, so I said to her, "It's already to an eighth of a wave. If you want, we could put a little extra time in it and get it to a sixteenth of a wave." She said, "What's the use? It's only a nine-incher!"

My hero! This is just to show how easily portable they are.

This is a little Sun telescope, and this is the front end of our big Sun telescope called Heliotrope. It used to operate at 93 power so you see the Sun as if you were one million miles away behind a big welder's glass. But if you were there, in five minutes the welder's glass would evaporate, and then you would go in the next three minutes. The Sun telescope out there shows you the Sun the way you'd see it from two million miles.

Here's the 24-incher at Fremont Peak with a ten and a little Sun telescope. Here's the twenty-four up at Glacier Point in Yosemite. That's where the Sidewalk Astronomers would like to see a permanent public observatory with something like fifteen or twenty eighteen-inchers. You cannot handle 400 people with one telescope in one evening. Don't flatter yourselves. It takes fifteen or eighteen eighteen-inchers to handle a crowd of several hundred people and get them all to see a whole lot of things on the same evening. With perhaps a dozen people in each line, and all telescopes pointed at Jupiter, one man with a bull horn can talk to them all about Jupiter. Then you turn them all to Saturn and talk about Saturn. You can have a lot of people in one evening and give a lot of information.

The problem is information. The reason — the only reason — I have even been interested in telescope making is because the people in this world have to see where the heck they live. They have to see it and they have to understand it.

Here we are at Glacier Point with the Sun telescope repainted.

Here we are at Buttonwillow. My old van broke down near Buttonwillow, and when Brian Rhodes pushed me in there to work on my engine, I set the Sun telescope up in the street. By evening I had made arrangements to go to the school the next day with the Sun telescope, and to give them all a slide show. The entire school got to look through the Sun telescope, and we got to see the murals in the halls. They belong to the Metropolitan Museum of Art. If you have the good fortune to break down in Buttonwillow while school is on, go and speak to the superintendent of schools — he's the principal, and there's only one school — and get in there and see the murals in those halls before they go.

A lot of you know Brian Rhodes. He and Jeff Roloff rebuilt my engine and we were out of there in two days.

This is Bruce Lusignan. He's in communications, and teaches at Stanford. Here he's building a sixteen-incher. See, he has a TV show to watch.

Here we are in the Sierras at seven thousand feet, at Soda Springs. This is the 24-incher, and this is Ruthie over here. That's an eighteen-inch unobstructed reflector. It has the diagonal mirror just inside the edge, and the light comes from the objective over to the side, hits the diagonal and goes immediately into the eyepiece.

Here is the black widow spider mount of the 24-incher. These pieces are garbage from the burned down hotel at Glacier Point. The first time we took the twenty-four there, I told Brian that that must be the best place in the world for a public observatory; but now there's that awful hotel there and there'll be mercury vapor lamps. We went there anyway and found that the hotel had just burned down. So this telescope has been there for more than 100 nights already. We've sized up the seeing conditions there for a lot of years, over a lot of nights, and it's a fabulous place for a public observatory. It's right at the top of a cliff. Whatever cold air comes down over it (and it's not very much) comes down through a forest very, very slowly and falls immediately off the cliff. It's cozy and warm there.

This is Thanksgiving Day. I'm down at Palo Alto to figure that 16 incher you saw a little while ago. I'm running my thumb around near the edge, with cerium oxide and water on there, to take down a hill near the edge.

This is Jeannie Lusignan pressing the pitch lap. These pictures are long ago.

Here we are at Death Valley. That is a very long focal length 16-incher. It's ten feet long, and it's called the Magnificat because it magnifies. This is Furnace Creek Visitor Center just about New Year's Day. He has hardware to put the two halves of his tube together. That whole telescope, and six of us, rode in that little camper.

Those are the Funeral Mountains behind us. This is below sea level. People sometimes ask us, "Why do you go below sea level?" We go below sea level because *you* go below sea level. We take the telescopes to where you go.

Here we're looking at Saturn. That's all.

If we had 500 Sidewalk Astronomers worldwide we could operate all summer long. We're not in conflict with the other groups; so join the other groups, but if you want to help out with telescopes for the rest of this world, come join us, too.

— John Dobson
San Francisco Sidewalk Astronomers
1600 Baker St.
San Francisco, CA 94115

Cassegrain and Schmidt-Cassegrain Light Shield Design

Cassegrain telescopes require light shields or baffles to prevent skylight reaching the focal plane and reducing image contrast. The light shielding may be designed for a specific fully-shaded field size. This field size may be larger or smaller than the unvignetted field. The graphical technique presented here will produce an almost optimal design with a fully shielded field and only an insignificant amount of vignetting. For simplicity, we allow a small amount of vignetting at the central obscuration which produces far less light loss than a corresponding cutoff of rays from the edge.

Design parameters affecting the system are:

1. *Primary f/ratio* — usually chosen for convenience between f/2 and f/4. Secondary considerations are the final field curvature and primary and secondary alignment requirements. Both are rapidly affected by a faster primary.

2. *Final f/ratio* — usually chosen for a compromise between focal length and photographic speed. For photoelectric photometry or spectroscopy, a slow f/ratio — typically near f/15 — simplifies instrument design.

3. *Field size* — chosen for photographic or instrumental reasons. For a small telescope — i.e., 8 inches — the field size should be at least 1 inch in diameter. Two criteria describe the field. How much of the field is unvignetted; that is, how far off-axis will a star be fully illuminated? The second criterion is how far off-axis you can go before direct sky light reaches the focal plane, reducing the image contrast? There is a necessary compromise between fully-shielded field size and the corresponding size of the central obscuration. The larger the shielded field, the larger the central obscuration becomes and the more light lost from the entire field. It is possible to design for a larger shielded field than the unvignetted field allowed by the size of the mirrors.

4. *Focal plane position* — usually the primary f/ratio, the final f/ratio, and the field size are specified, but these are not sufficient: the position of the final focus must also be known. The focal plane may be moved through a considerable distance by changing the spacing between the primary and the secondary mirrors; however, there is a degradation of the image quality.

5. *Aperture stop position* — Cassegrain telescopes have their aperture stop at the primary mirror. The Schmidt corrector plate is the aperture stop for most Schmidt-Cassegrains. This affects the size of the primary and secondary mirrors and their light shields.

Shielding Design

I. The first step in the design process is to specify the optical design parameters. You then make a scale drawing, preferably with the scale along the optical axis compressed to ½ to ⅓ the scale used for the diameters. This has the effect of making the system faster, resulting in larger angles for the ray interactions, and thereby produces better accuracy. The final result can then be properly scaled to give the diameters and lengths for the shields.

II. The design field size is drawn at the Cassegrain focus position, and the equivalent field size drawn at the prime focus. This equivalent size is equal to the Cassegrain field divided by the amplification (effective focal length divided by the focal length of primary).

Figure 1 shows these along with the rays required for imaging the field. Ray 2 is imaged on axis at the Cassegrain focus and at the prime focus. Rays 1 and 3 define the full field of the design. The design process will use rays 3 and 4 to determine the shielding.

III. Draw ray 3 from the edge of the primary to the edge of the prime focus field. This ray determines the size of the secondary mirror. Ray 3 may be continued to the Cassegrain focus as ray 3′.

IV. Construct ray 4 assuming some diameter for the secondary shield. For simplicity, draw this ray parallel to the optical axis. Ray 4 is reflected from the primary and intersects the optical axis at the prime focus (point A). The intersection of ray 4 (reflected from the primary) and ray 3 (reflected from the secondary) defines the theoretical front position and diameter of the primary light shield. Due to the finite thickness of the shield tube, the actual location will be slightly behind this point.

V. The secondary shield is defined in location and diameter by the intersection of ray 3 (reflected from the primary) and ray 4 (point B). A line connecting points A and B, and modified for actual thickness of the shields, defines the shielded ray which separates the shielded field from the unshielded sky.

Comments on Shielding Schemes

The shaded area in figure 1 has no field free from skylight. Figure 2 has slightly more shielded field than required. This was obtained by making the secondary light shield larger than necessary, or a similar effect can be achieved by making the primary shield longer, but both increase the size of the central obscuration. Points A and B have both changed from figure 1 giving a new shielded ray. At the Cassegrain focal plane, any point between the optical axis and the shielded ray is shielded from the stray light.

A small reduction in the diameter of

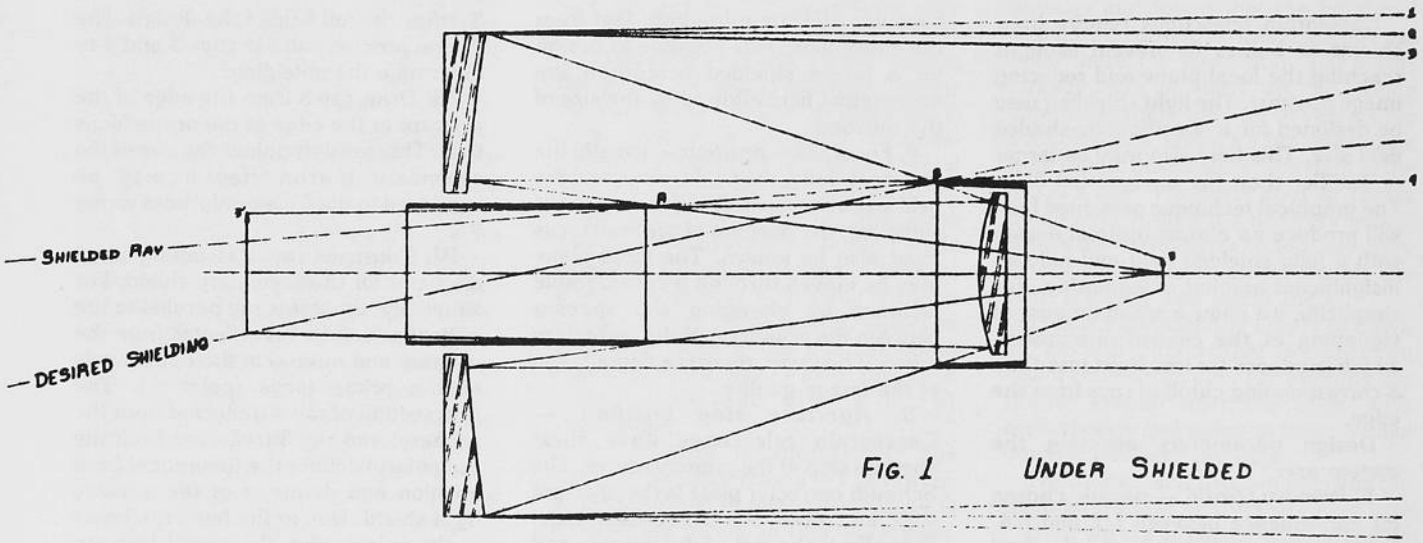


FIG. 1 UNDER SHIELDED

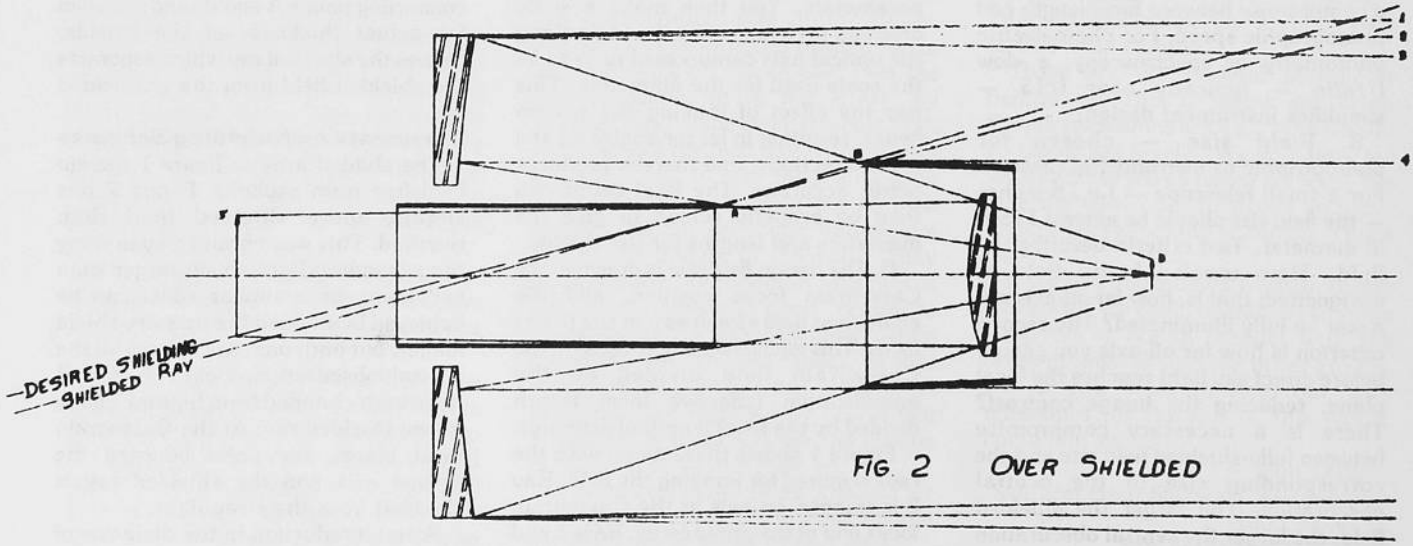


FIG. 2 OVER SHIELDED

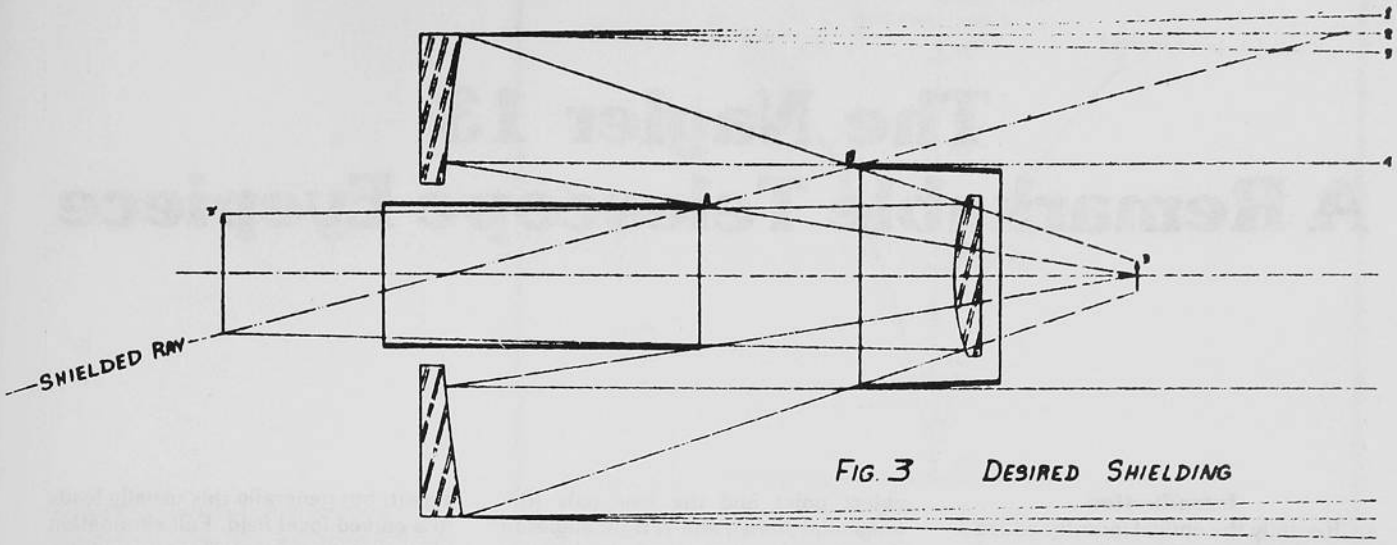


FIG. 3 DESIRED SHIELDING

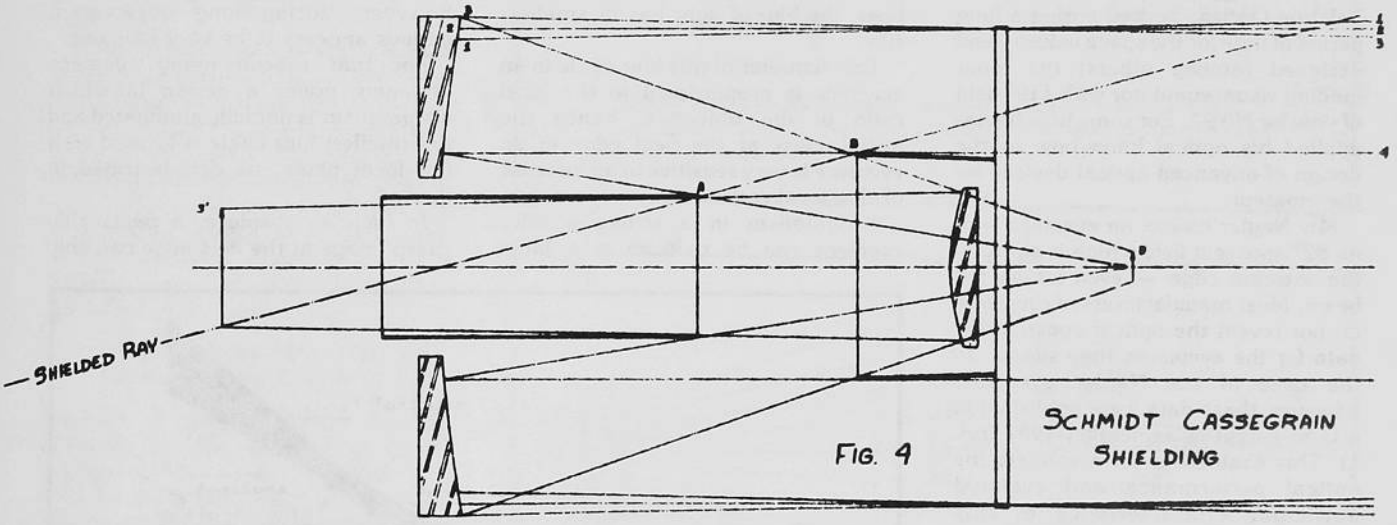


FIG. 4 SCHMIDT CASSEGRAIN SHIELDING

the secondary shield results in the desired shielding shown in figure 3. Note that the central obscuration and hence the light loss is determined by both the secondary light shield diameter and the diameter and position of the primary shield.

The fully shielded field may be increased by extending the primary light shield and slightly increasing its diameter. Under these conditions, the central obscuration diameter is determined by the primary shield and will be larger than the diameter of the secondary light shield because the extension of the primary shield prevents ray 4 (reflected from the primary) reaching the secondary. This technique is commonly used in commercial Schmidt-Cassegrain telescopes since it gives the illusion of a smaller central obscuration. The additional light loss, however, can be considerable. It is more efficient to use properly sized shields. The only advantage of this technique is that the obscuration appears to be smaller and is easier to sell to the public.

Figure 4 shows a shielding design for a Schmidt-Cassegrain. Rays 1, 2, and 3 are slightly different due to the aperture stop being at the connector plate. This results in light shields which are slightly larger in diameter but have almost the same positions as the standard Cassegrain. The primary and secondary mirrors must also be larger to prevent vignetting due primarily to the position of the aperture stop and only slightly due to the deviation of the rays by the corrector plate. The light shields for a Maksutov-Cassegrain are similar to those in the Schmidt-Cassegrain.

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The Nagler 13
A Remarkable Telescope Eyepiece

Introduction

Recently the optical industry added a remarkable new piece of optics to the many products which came on the market for the amateur: the Nagler 13 telescope eyepiece, with a focal length of 13mm.

The designer, Albert Nagler of TeleVue Optics, worked during a long period of time for the space industry and designed (among others) the lunar landing visual simulator with 110° field of view for NASA. For some time he has applied his optical know-how to the design of advanced optical devices for the amateur.

Mr. Nagler claims an eyepiece with an 82° apparent field which is sharp to the extreme edge — even for an f/4 beam. Most manufacturers of eyepieces do not reveal the optical construction data for the eyepieces they supply. In the case of the Nagler eyepiece, however, these data were published in a U.S. patent in September 1981 (ref. 1). This enabled us to investigate the optical performance and eventual particular characteristics of this eyepiece by means of optical ray tracing.

In this article we will describe the special construction of the eyepiece, and we will make a comparison with a wide-field modified Erfle eyepiece. The last mentioned type of eyepiece is used by many amateurs at present. Before explaining the working principle of the Nagler, it seems useful to go into the main cause of edge unsharpness in wide-field eyepieces: astigmatism.

Astigmatism

Generally speaking, good image sharpness in a wide-field eyepiece is limited to a field of view of approximately 50°, mainly as a result of astigmatism. Astigmatism in a lens is caused by the difference in refractive power of that lens in a plane through the object point and the lens axis (the tangential plane), and at right angles to that plane (sagittal plane). In this way two focal lines are formed, one in the tangential plane and one in the sagittal plane which are perpendicular to each other (figure 1). In the middle between the tangential and the sagittal force lines, the blur of light has its smallest size.

The diameter of this blur circle in an eyepiece is proportional to the focal ratio of the objective, hence the unsharpness at the field edge of an eyepiece is very sensitive to an increase of this focal ratio.

Astigmatism in a strong positive eyepiece can be reduced to a large extent, but generally this usually leads to a curved focal field. Full elimination of astigmatism in combination with a flat focal field is not possible in normally used eyepieces. To some extent, curvature of field is compensated for by the accommodation power of the eye. Strong accommodation of the eye, however, during long observation periods appears to be very fatiguing.

For that reason many eyepiece designers prefer a design in which astigmatism is not fully eliminated and the smallest blur circle is located on a flat focal plane, as demonstrated in figure 2.

In such an eyepiece, a reasonably sharp image at the field edge can only

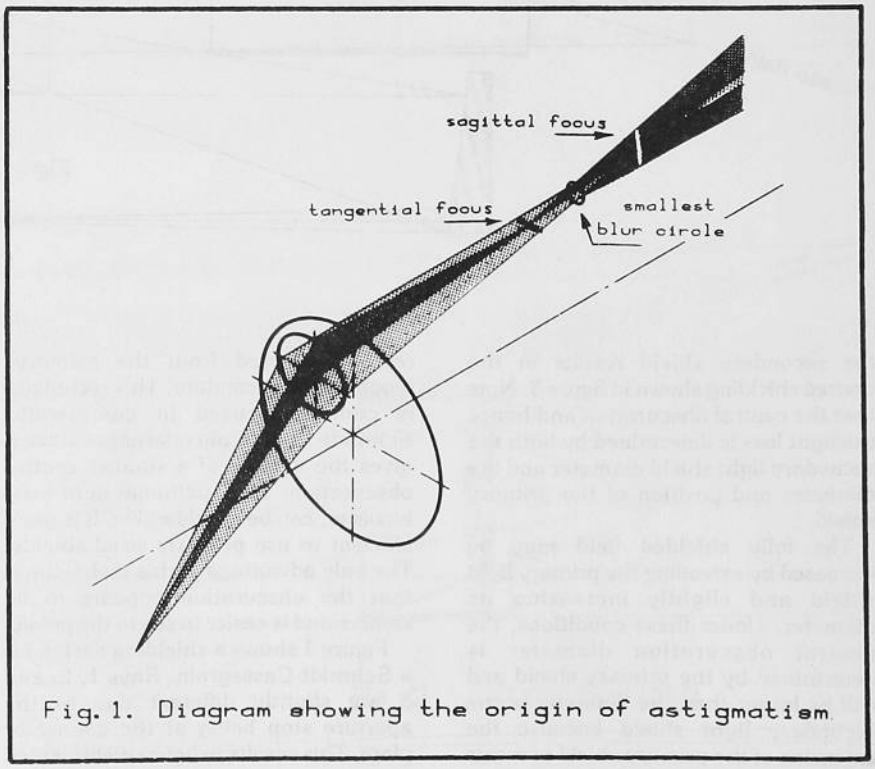

Fig. 1. Diagram showing the origin of astigmatism

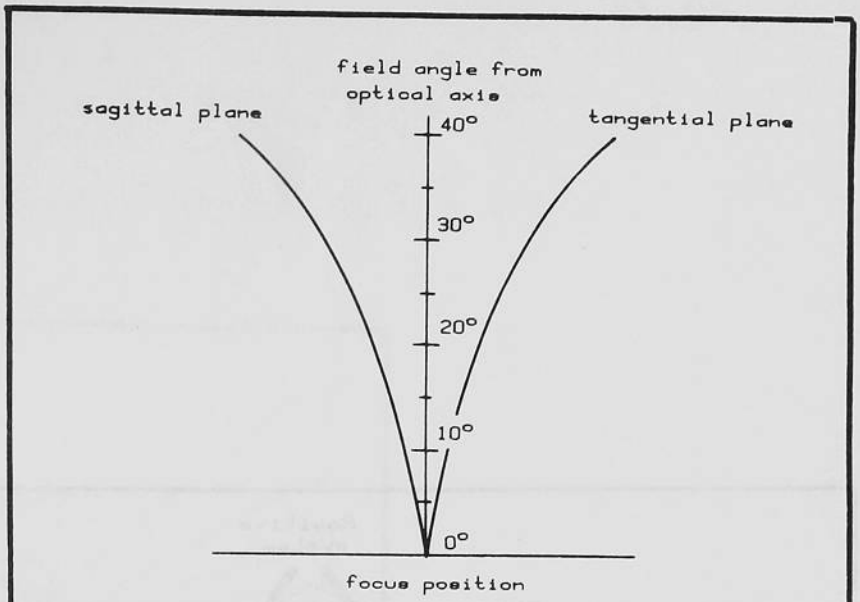

Fig. 2. Curves of saggital and tangential planes for a wide field telescope eyepiece with a flattened focal plane

(NOTE: These are merely generalised curves and do not specifically refer to the Erfle design we reviewed in this article.)

be obtained when the focal ratio of the objective is long, for instance f/15. For short focal ratios, f/5 say, the blur circle blows up proportionally — resulting in a considerable fuzziness toward the edge. In this case, the outer field is useful only for identifying the presence of a possible target and not for observation.

In recent years there has been a trend toward the use of mirrors with focal ratios between f/4 and f/6, and f/4 to f/6 refractors are also marketed today. From the foregoing, it should be clear that the normal wide-field eyepieces are not satisfactory for these telescopes, and it could have been expected that sooner or later someone would discover this "market gap" and design an eyepiece suited for short focal ratios.

The Working Principle of the Nagler Eyepiece

Figure 3 gives a cross-sectional drawing of the Nagler eyepiece compared with a six-lens modified Erfle with the same focal length, both at the same scale. Striking points are the large number of lenses (7) and the relatively large dimensions of the Nagler. Contrary to most modern eyepieces, the eyepiece diaphragm of the Nagler is placed between the lenses.

In order to demonstrate the basic principle of the Nagler eyepiece, we reduce it to its simplest form, as shown in fig. 4. To the left side of the stop is a negative lens and to the right side of the stop a positive lens. As we mentioned before, it is possible to reduce astigmatism in a strong positive eyepiece system to a large extent at the cost of introducing curvature of field. When, however, a negative lens is placed between the objective and the positive eyepiece lens, the field curvature of the positive lens can be compensated by the field curvature of

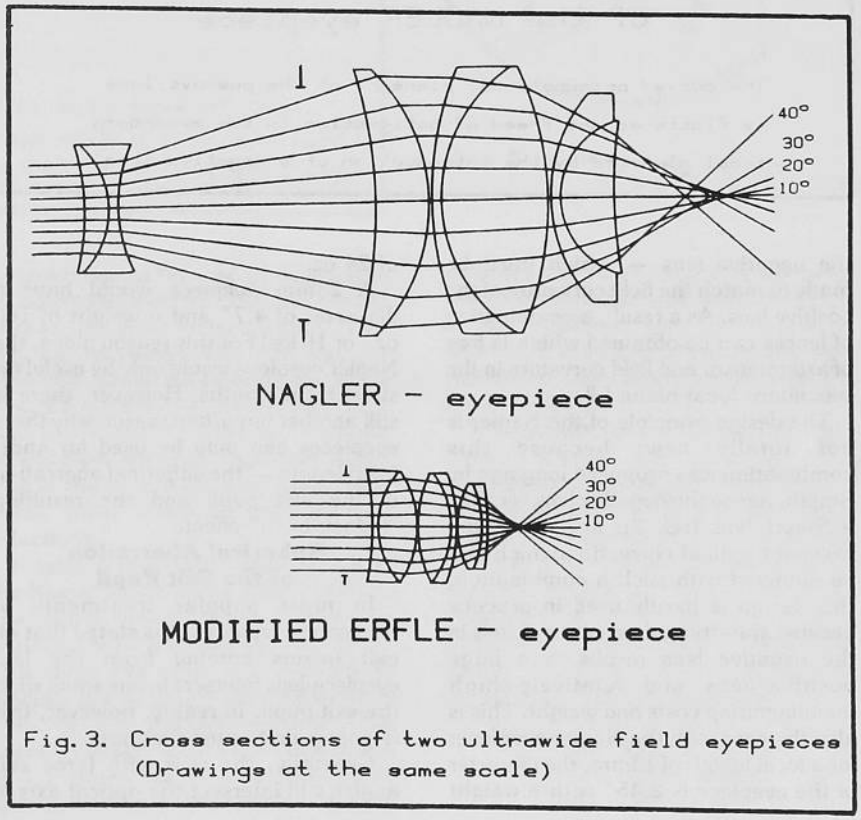

Fig. 3. Cross sections of two ultrawide field eyepieces (Drawings at the same scale)

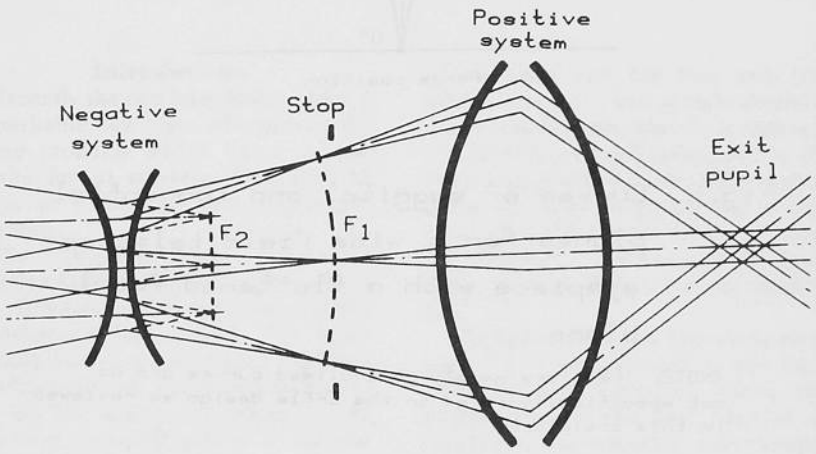

Fig. 4. Basic principle scheme of the NAGLER eyepiece

The curved primary focal plane F1 of the positive lens is flattened and freed of astigmatism in the secondary focal plane F2 by the introduction of a negative lens

the negative lens — which must be made to match the field curvature of the positive lens. As a result, a combination of lenses can be obtained which is free of astigmatism and field curvature in the secondary focal plane F2.

The design principle of the Nagler is not totally new; because this combination was proposed long ago by Smyth, hence the negative lens is called a Smyth-lens (ref. 2). In spite of the excellent optical correction which can be obtained with such a combination, this design is hardly used in practice because the strong divergence of rays in the negative lens results in a large positive lens and relatively high manufacturing costs and weight. This is also the case with the Nagler eyepiece: for a focal length of 13mm, the diameter of the eyepiece is 2.45″ with a weight of 24 oz.

A 25mm eyepiece would have a diameter of 4.7″ and a weight of 160 oz., or 10 lbs! For this reason alone, the Nagler eyepiece would only be useful for short focal lengths. However, there is still another important reason why these eyepieces can only be used for short focal length — the spherical aberration of the exit pupil and the resulting "kidney bean" effect.

Spherical Aberration of the Exit Pupil

In most popular treatments of telescope eyepieces, it is stated that all exit beams coming from the last eyepiece-lens intersect in one small spot: the exit pupil. In reality, however, this is only a first approximation.

Generally, the rays with large exit angles will intersect the optical axis in points nearer to the last eyepiece lens than rays with moderate or small exit angles. This effect is called spherical aberration of the exit pupil.

For eyepieces with moderate apparent fields, for instance 50°, and short focal lengths, generally this effect will not be detrimental. For ultra-wide-field eyepieces, however, this situation can be different. Figure 5 shows a large-scale drawing of the last eyepiece lens of the Nagler 13 eyepiece with some exit rays. It is shown here that there is a certain shift of the intersecting points with the optical axis when the exit angle increases. As a consequence, in order to be able to catch all exit rays, the eye pupil must have a certain minimal diameter, corresponding with the smallest cross section, which is 3.5mm. In figure 5, only the principal rays of the exit beams are drawn. In reality the exit-beams will have a certain thickness, for instance approximately 3mm for a f/5 beam. The smallest cross section of all exit beams together will then amount to 3.5 + 3 = 6.5mm. This means that the Nagler 13 eyepiece should be applied during night observation when the eye pupil is wide open.

When the eyepiece is used during daytime, with an eye pupil of 2 to 3mm, some of the exit beams will not reach the retina.

Parts of the image, therefore, will not be visible and dark shadows will move through the field. Some users find this annoying. The effect is called "kidney bean" effect because of the shapes of the shadows (figure 6).

When the focal length of a certain eyepiece is increased, all dimensions are proportionally increased. This is also the case for the diameter of the above mentioned smallest cross section of the exit beams.

The maximum diameter of the eye

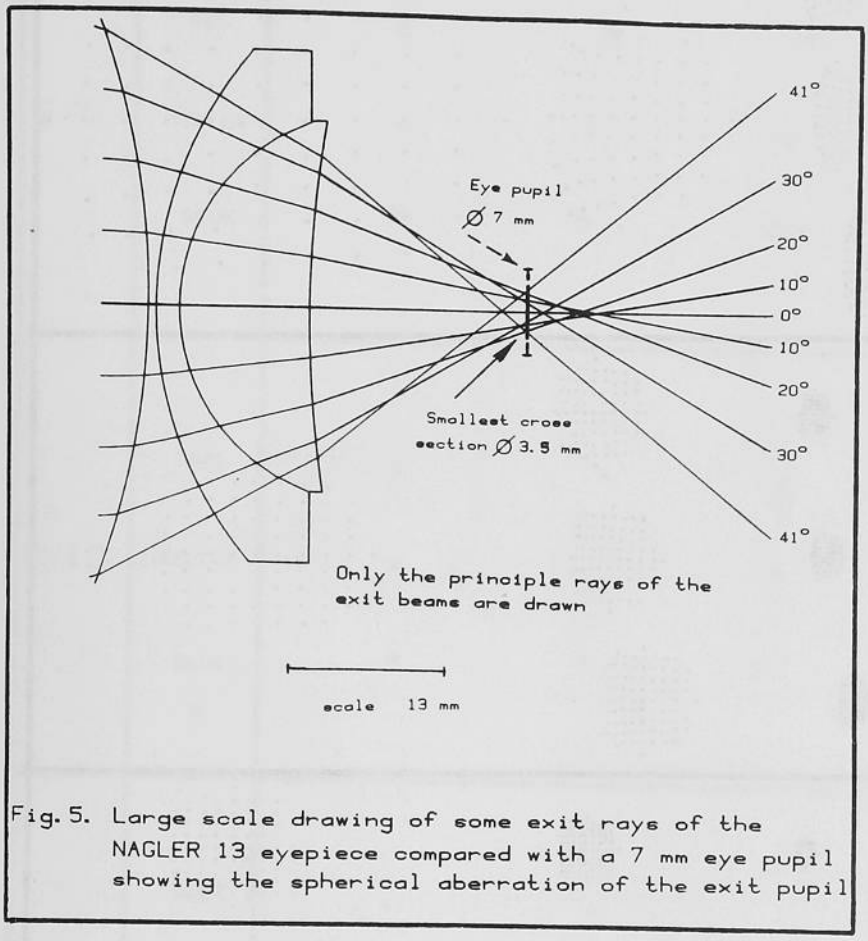

Fig. 5. Large scale drawing of some exit rays of the NAGLER 13 eyepiece compared with a 7 mm eye pupil showing the spherical aberration of the exit pupil

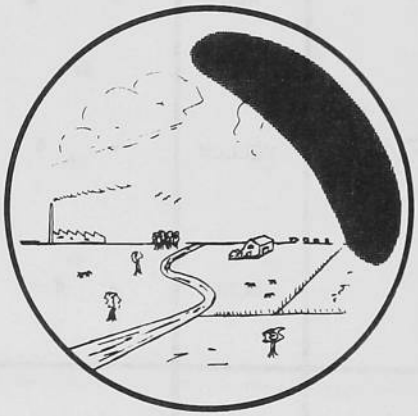

Fig. 6. Kidney bean effect

pupil, however, remains the same. Hence the focal length of the Nagler is restricted to a maximum of approximately 13mm, the longest focal length which permits all light to pass through the 7mm pupil of the eye during night observation. For Nagler designs with smaller focal lengths, the situation concerning the kidney bean effect is more favorable. This is not only true for daytime observation, but also for elderly persons for night observation, because for these individuals the maximum diameter of the dark-adapted pupil will be smaller than the above mentioned 7mm. Therefore, TeleVue supplies also Nagler eyepieces with focal lengths of 9mm and 4.8mm in which the kidney bean effect is reduced or eliminated.

Generally speaking, the spherical aberration of the exit pupil in an eyepiece can be reduced by building in an aspherical element. This will greatly increase the manufacturing costs. This may be the reason why this was not done here. About the construction of the Nagler the following can be remarked: only two kinds of common, ordinary optical glass are used. Moreover, some radii of the optical surfaces were made equal. Both measures lead to cost reductions.

Finally, a favorable characteristic of the Nagler 13 should be mentioned: the eye relief amounts to 17mm — remarkable for a focal length of 13mm. This large eye relief was realized by placing the negative lens element in front of the positive element. The positive element itself has a focal length of 1.7 times the e.f.l. of the whole system, or 22mm. The negative element enlarges the focal length of the used telescope objective with a factor of 1.7, so the combined eyepiece obtains a short focal length, whereas the eye relief (which belongs to the positive element) remains large.

The eye relief of the 13mm wide-field Erfle, which we checked for comparison, amounts to only 8mm.

Results of Optical Ray Tracing

Based on the data given in table 1, we analyzed the optical performance of both the Nagler 13 and a modified six element Erfle of the same focal length, by means of optical ray tracing. The checked off-axis image angles were 0°, 10°, 20°, 30°, and 40° and colors:

red = 656.27 nm
yellow = 587.56 nm
blue = 486.13 nm

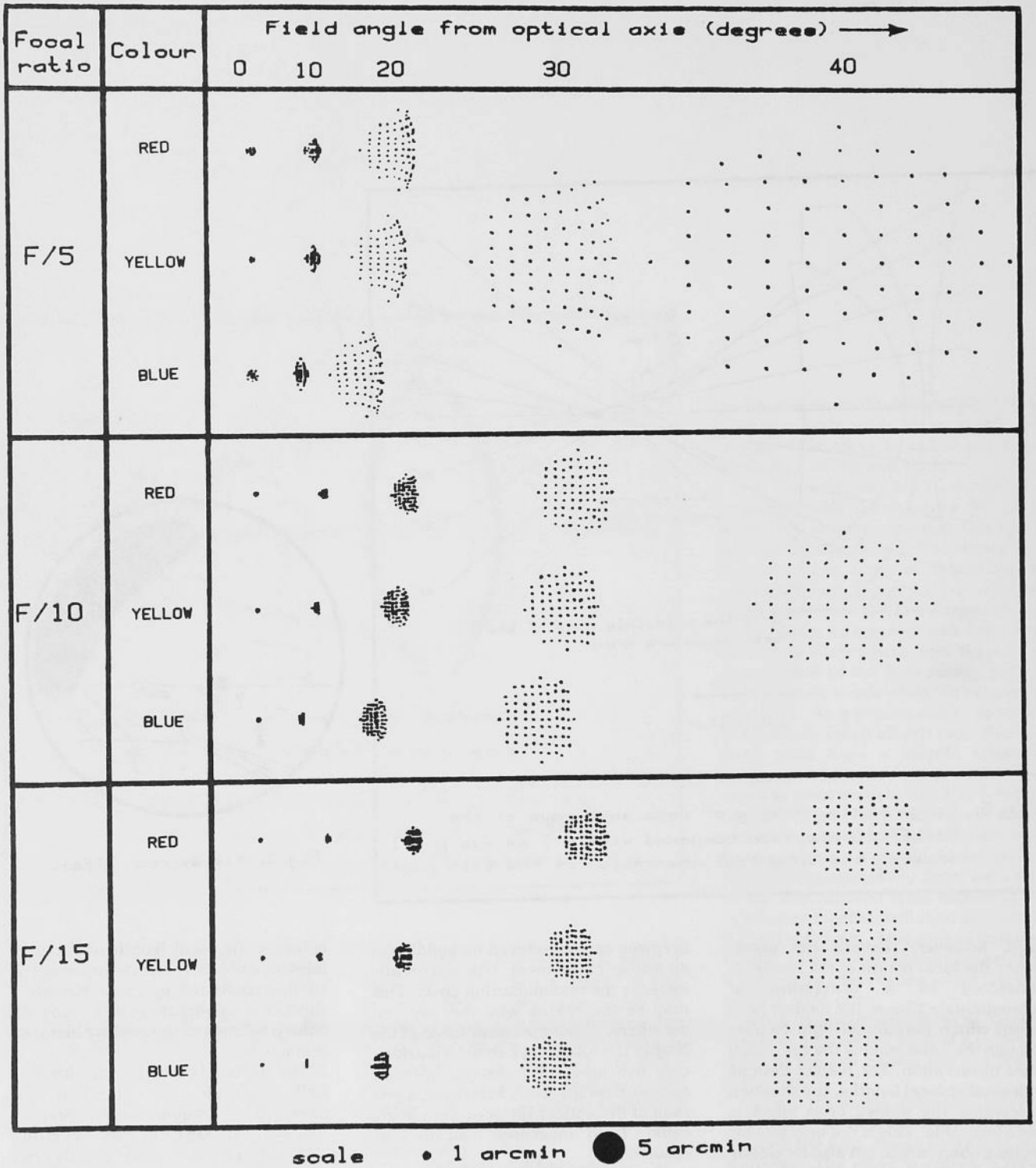

Fig. 7. Spot diagrams for various field angles and F-ratios for the six lens modified ERFLE eyepiece

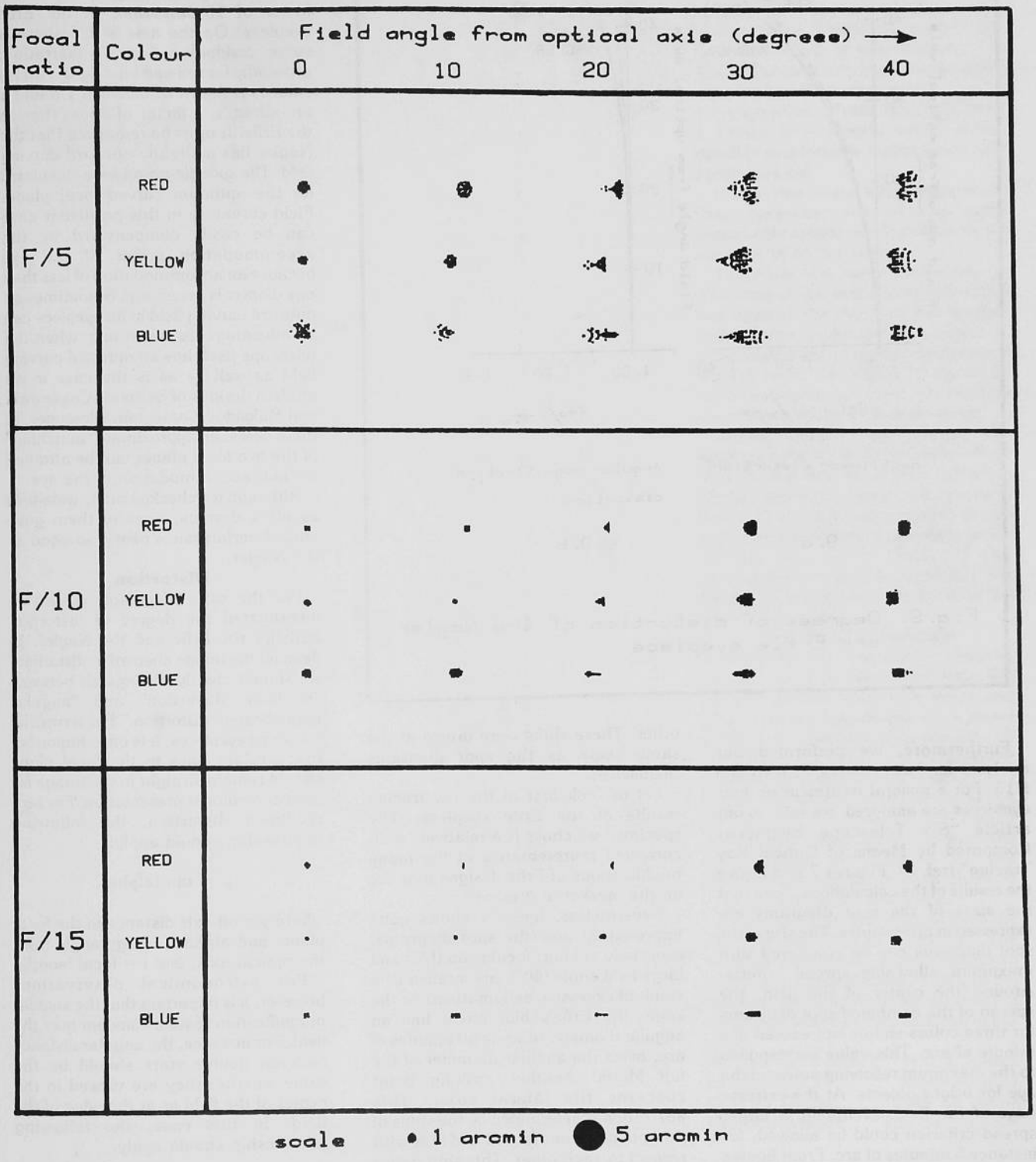

Fig. 8. Spot diagrams for various field angles and F-ratios for the NAGLER eyepiece

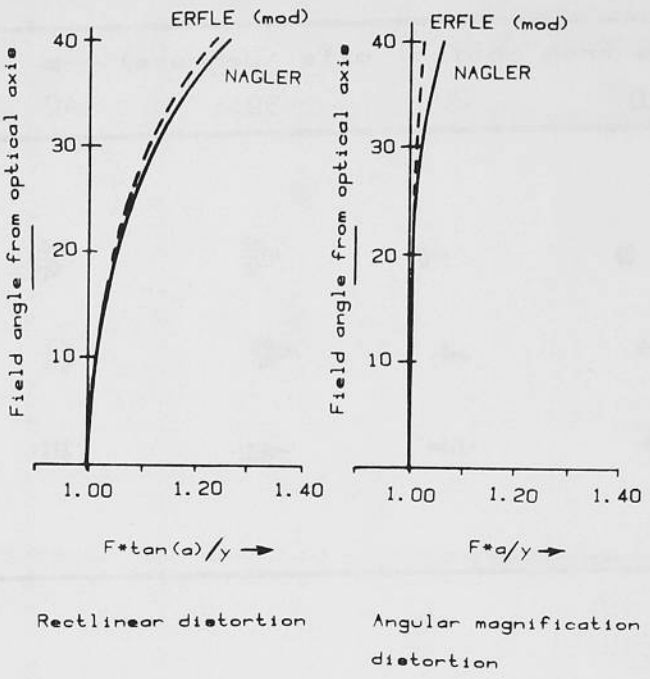

Fig. 9. Degrees of distortion of the Nagler and Erfle eyepiece

Furthermore, we performed our analyses for focal ratios f/5, f/10 and f/15. For a general treatment on how eyepieces are analyzed, we refer to our article "Six Telescope Eyepieces Compared by Means of Optical Ray Tracing" (ref. 3). Figures 7 and 8 give the results of the calculations. Note that the sizes of the spot diagrams are expressed in arc-minutes. The size of the spot diagrams can be compared with maximum allowable spread criteria. Around the center of the field, the spread of the combined spot diagrams for three colors should not exceed one minute of arc. This value corresponds to the maximum resolving power of the eye for bright objects. At the extreme edge of the field, eventually a larger spread criterion could be allowed, for instance 5 minutes of arc. From figures 7 and 8, lateral color can be judged as well. Lateral color means that the image scale outside the optical axis depends on the color of the light.

This aberration expresses itself by color fringes outside the optical axis. Lateral color will occur when the spot diagrams for various colors have been drawn shifted with respect to each other. These shifts were drawn at the same scale as the spot diagrams themselves.

Let us look first to the ray tracing results of the Erfle eyepiece. The specimen we chose is a relatively well-corrected representative of the many modifications of Erfle designs that are on the market at present.

Nevertheless, figure 7 shows quite impressively how the spot diagrams, especially at short focal ratio (f/5) and large field angle (40°), are swelled as a result of excessive astigmatism. At the edge, the Erfle's blur circle has an angular diameter of some 60 minutes of arc, twice the angular diameter of the full Moon! Another striking point concerns the lateral color. This aberration is determined by the shifts of the spot diagrams for red and blue with respect to each other. This shift varies between 5 and 9 minutes of arc for the Erfle. Correction of lateral color seems to be difficult in Erfle eyepieces, because all the Erfle designs we checked suffer from this aberration.

In figure 8, the spot diagrams for the Nagler are shown. It is quite impressive to see how far astigmatism could be suppressed in this design: for a moderate field angle (20°) a factor of 6, and for a large field angle (40°) even a factor of 10 less than in the Erfle eyepiece! On the axis at f/5 there is some residual spherical aberration, especially for red and blue light. Lateral color is rather low: between 1.5 and 3 arc-minutes, a factor of 3 less than in the Erfle. It must be remarked that the Nagler has a slightly outward curving field. The spot diagrams were calculated for the optimum curved focal plane. Field curvature in this particular case can be easily compensated by the accommodation power of the eye because an accommodation of less than one diopter is necessary. Sometimes an outward curving field in an eyepiece can be advantageous, especially when the telescope itself has an outward curving field as well — as is the case in all modern designs of Schmidt-Cassegrain and Maksutov-Cassegrain telescopes. In these cases, an approximate "matching" of the two focal planes can be attained without accommodation of the eye.

Although we checked many wide-field eyepiece designs, none of them gave optical performance nearly so good as the Nagler.

Distortion

For the sake of completeness, we investigated the degree of distortion both for the Erfle and the Nagler. In defining the image aberration distortion, we should clearly distinguish between "rectinear distortion" and "angular magnification distortion." For terrestrial telescope eyepieces, it is often important that straight lines in the focal plane should remain straight in the image for correct rectlinear presentation. For zero rectlinear distortion, the following relationship should apply:

$$y = f \tan(\text{alpha})$$

where y = off-axis distance in the focal plane, and alpha = image angle from the optical axis, and f = focal length.

For astronomical observation, however, it is important that the angular magnification remain constant over the field. For instance, the angular distance between double stars should be the same whether they are viewed in the center of the field or at the edge of the field. In this case, the following relationship should apply:

$$y = f \times \text{alpha}$$

In the case of zero angular magnification distortion, it is inevitable that straight lines in the focal plane appear curved like a pincushion with the curvature becoming greater the farther they lie from the center. It is impossible to correct an eyepiece simultaneously

Table 1. Optical characteristics of the Erfle and Nagler eyepieces based on a focal length of 10 mm (For the Nagler 13 multiply all data with the factor 1.3)

	Erfle	Nagler
R1 (radius of curvature)	- 46.6	- 37.6
T1 (axial thickness or distance)	0.91	3.8
M1 (medium)	SF 2	SF 1
R2	13.15	- 14.0
T2	6.14	1.5
M2	BK 7	SK 16
R3	- 15.6	23.5
T3	0.09	40.5 (= 29.6 + 10.9)
M3	Air	Air
R4	19.45	- 75.6
T4	5.22	8.4
M4	BaK 7	SK 16
R5	- 14.1	- 29.9
T5	0.9	0.5
M5	SF 10	Air
R6	- 24.7	52.9
T6	0.09	1.5
M6	Air	SF 1
R7	14.3	25.2
T7	3.87	16.8
M7	BaK 5	SK 16
R8	- 16.8	- 52.9
T8	0.91	0.5
M8	SF 10	Air
R9	- 45.1	25.2
T9		1.5
M9		SF 1
R10		12.7
T10		8.4
M10		SK 16
R11		75.6
Distance last lens to exit pupil	approx. 6	approx. 13

for rectlinear distortion and angular magnification distortion.

Figure 9 gives the results of our calculations. Rectlinear distortion for both eyepieces is considerable, but angular magnification distortion, which is relevant for astronomical viewing, is very low and probably invisible.

Summary

The Nagler 13 telescope eyepiece has some remarkable advantages but also has its limitations.

The advantages can be summarized as follows:

- the eyepiece has a 82° wide field with an unexcelled image sharpness to the extreme edge. This is true even for fast focal ratios, f/5 or even higher;
- lateral color is very low compared with other wide-field eyepieces;
- the eye relief, 17mm, is very large for a 13mm focal length, which makes possible comfortable viewing even with eyeglasses on.

In our view these advantages make this eyepiece one of the most remarkable optical developments for the amateur in recent years.

There are also some limitations:

- because of the optical principle which was applied, the eyepiece has become rather large, bulky and expensive;
- because of the spherical aberration of the exit pupil, the Nagler 13 should be used preferably for night observation when the eye's pupil is wide open.

During daytime observation, the eyepiece exhibits the kidney bean effect. This is reduced or eliminated when Nagler eyepieces with shorter focal length (9 and 4.8mm) are used. At the night sky the kidney bean effect is not visible, but as a result of the construction principle applied, the Nagler eyepiece can only be built for short focal lengths.

Concluding Remarks

The foregoing evaluation is based on data given in the patent publication. We are aware that there is a some risk involved in this type of analysis. A patent protects the principles of an invention on the basis of the data of a prototype, but between the application of a patent and its publication lies a considerable period of time (in the case of the Nagler approximately two years). However, the development goes on — so the production model will often be changed with respect to the prototype.

We understand that this has been the case for the Nagler eyepiece. The designer made some slight changes to improve the lateral color. This will be, of course, advantageous for the user but should not affect the conclusions of our study.

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Literature References

1. US patent 4,286,844. September 1981
2. *Die Fernrohre und Entfernungsmesser*, Konig/Kohler, page 173
3. *"The Optical Performance of Six Telescope Eyepieces,"* H.G.J. Rutten and M.A.M. van Venrooij, TM#19

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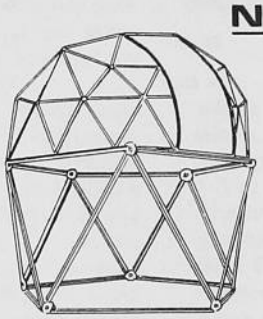

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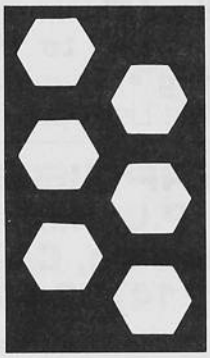

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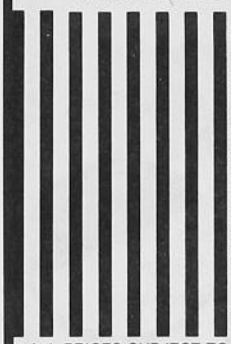

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DEEP-SKY FILTER™

Photo by Dr. J. Marling, 8"f/4.5, 60 min. hypered 2415

Rosette Nebula photo with a Deep-Sky Filter Visually, this is best seen with a UHC Filter.

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**Premium filters are selected best of the lot and typically have 5-10% high transmission. Not always available. Include individually measured transmission data.*

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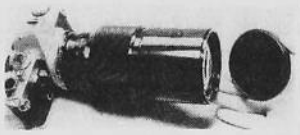

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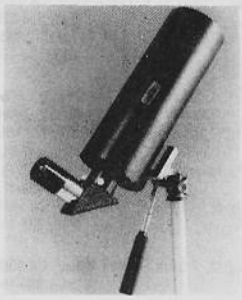
LUMICON SUPER-FINDER™



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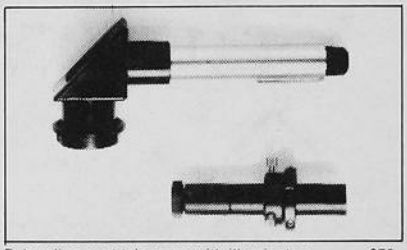

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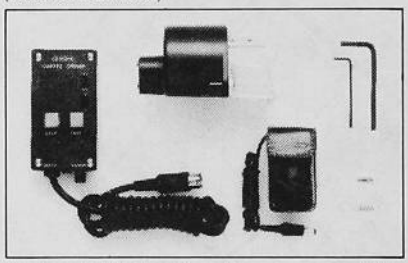

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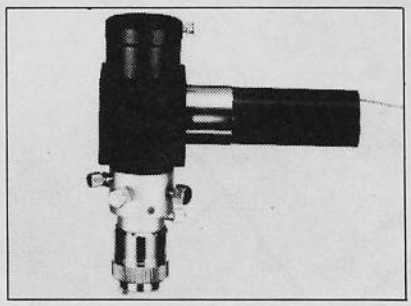

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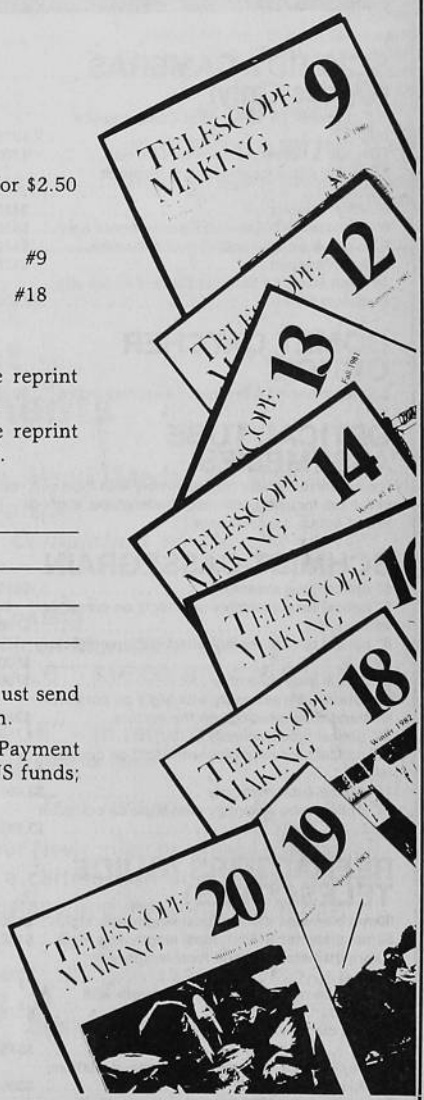

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